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PASP PLUS TRANSIENT PULSE MONITOR (TPM) - PREFLIGHT CHARACTERIZATION REPORT

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13. ABSTRACT *(Maximum 200 words)*
The Transient Pulse Monitor (TPM), part of the PASP Plus experiment aboard the APEX spacecraft, is designed to detect and characterize electromagnetic transient signals produced by electrostatic discharges on the solar array test modules. However, as a result of the way in which the TPM electric-field sensors are installed on the APEX spacecraft, certain additional information is required to properly analyze and interpret mission data relating to the locations of discharges that may occur. The purpose of the TPM E-Field Sensor Response Characterization Test was to perform a series of preflight measurements on the as-installed sensor/payload configuration. The measurements were made to determine the relative combined responses of the entire set of E-field sensors to electromagnetic signals originating at selected locations on the deployed panel and payload shelf. These data will then be used, during the data analysis phase of the PASP Plus program, to help determine the actual discharge locations. This report describes the TPM E-Field Sensor Response Characterization Test results, and, based upon these results, the development and testing of preliminary flight data analysis techniques and software prior to launch.

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ABBREVIATIONS

APEX	Advanced Photovoltaic and Electronics Experiments
E-field	electric field
ESDs	electrostatic discharges
GSE	Ground Support Equipment
PL	Phillips Laboratory
TPM	transient pulse monitor

1. INTRODUCTION

1.1 PROGRAM OBJECTIVES

SRI International's present PASP Plus contract addresses two separate but related tasks:

- **Task 1**: Preflight integrated transient pulse monitor (TPM) system characterization involving the performance of a series of tests of the TPM system as installed on the Advanced Photo-voltaic and Electronics Experiments (APEX) spacecraft to ensure that TPM mission data can be properly analyzed and interpreted to determine the locations and characteristics of arc discharges on the solar array modules.
- **Task 2**: Post-flight TPM data analysis in which the SRI personnel responsible for the TPM design, fabrication, and characterization will perform the analysis and interpretation of TPM mission data to maximize the usefulness of the overall PASP Plus mission results.

As originally planned, Task 1 was to be completed just before launch, and Task 2, including development of flight-data processing and analysis techniques, was to have been performed after launch during the actual flight-data analysis period. Fortunately, delays in the original APEX launch schedule have allowed time for the development and testing of preliminary flight-data analysis techniques and software, based upon the Task 1 test results, prior to launch. This effort is in progress.

1.2 SCOPE OF THIS REPORT

This report describes the plan, performance, and test results obtained from Task 1, and is intended as the final deliverable item for that task. In addition, it describes the preliminary results of the ongoing flight-data analysis technique development effort.

2. PREFLIGHT TPM CHARACTERIZATION TEST

2.1 TEST PLAN

This section contains the relevant portions of the preflight TPM characterization test plan both for completeness and as a reference for the following sections.

2.1.1 Background and Purpose of Test

The TPM and its associated electric-field (E-field) sensors were extensively tested and calibrated before delivery to Phillips Laboratory (PL) for integration into the PASP Plus experiment and the APEX spacecraft. The TPM E-field sensors are designed to detect and

characterize the amplitudes, derivatives, and absolute integrals of transient E-fields at the sensors' locations normal to the electrically conductive surface upon which the sensors are mounted. For absolute calibration, these sensors were exposed to uniform, large-area, normally incident electromagnetic-field transients of known waveforms and amplitudes in a parallel-plate transmission line. The response characteristics of the sensors themselves are therefore well understood.

However, as a result of the way in which the sensors are installed on the APEX spacecraft, certain additional information is required to properly analyze and interpret mission data relating to the locations and characteristics of electrostatic discharges (ESDs) that may occur on the various solar array modules. Figure 1 shows the locations of the four TPM E-field sensors on the payload shelf and on the deployed panel. If a discharge occurs on one of the solar array modules, each E-field sensor will respond to the resulting electromagnetic-field transient at the sensor's particular location. Depending upon the distance from the discharge source and the nature of the discharge, the E-field on a large, uniform ground plane varies inversely as the square or cube of the distance to the source. For the APEX installation, however, the relative sensor responses will be complicated by several effects including reflections from panel and payload shelf edges, possible resonances of the Langmuir probe and magnetometer booms, and the exact relationship between the sensor and the discharge locations.

The purpose of the TPM E-Field Sensor Response Characterization Test is to perform a series of preflight measurements on the as-installed sensor/payload configuration to determine the relative combined responses of the entire set of E-field sensors to electromagnetic signals originating at selected locations on the deployed panel and payload shelf. The electromagnetic signals generated by the E-field stimulus in these tests is not intended to simulate precisely the characteristics of actual discharges, but rather to determine the responses of the TPM E-field sensors to low-level, broadband fields radiated from specific locations on the spacecraft. These data will then be used, during the data analysis phase of the PASP Plus program, to help in the determination of actual discharge locations.

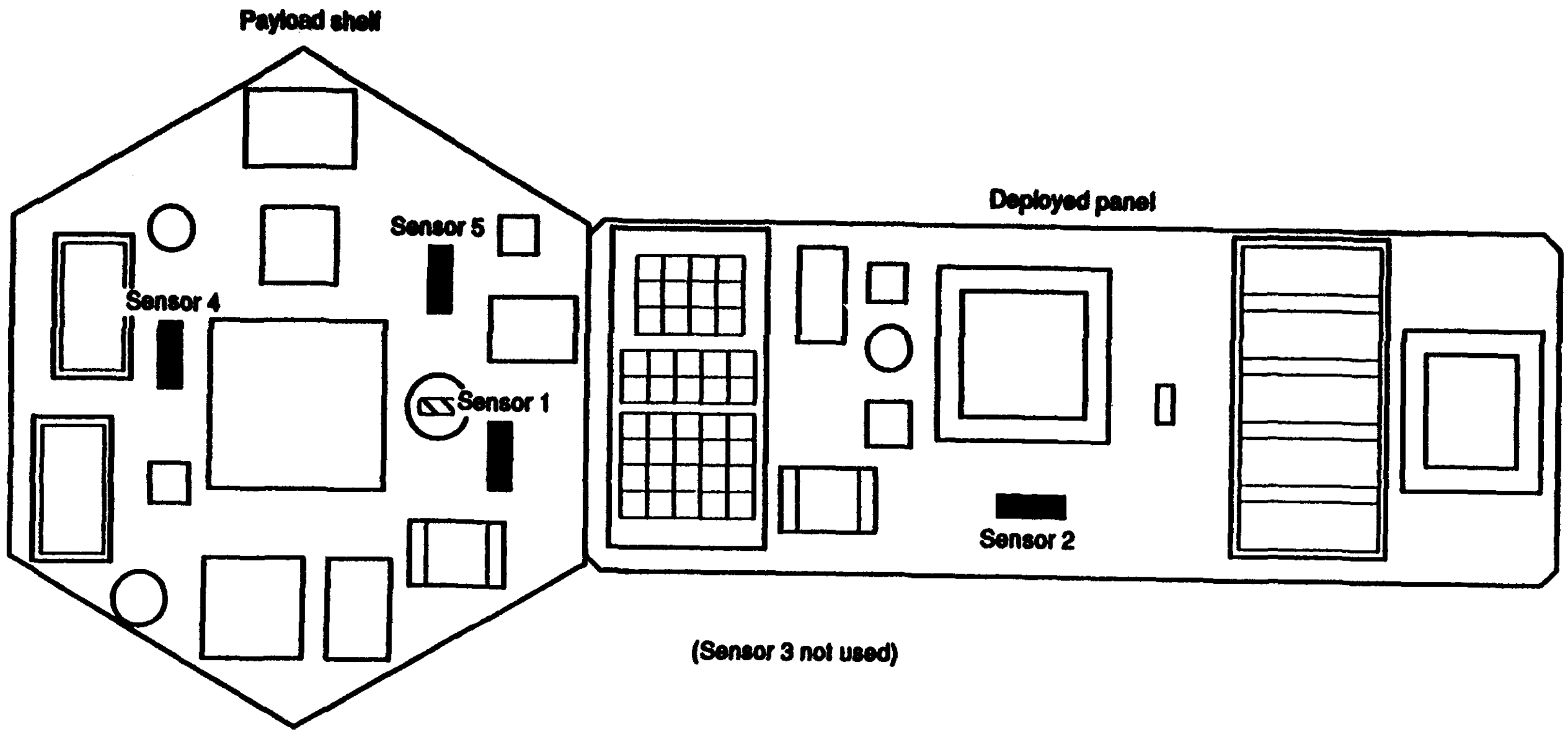

Figure 1. TPM SENSOR LOCATIONS

2.1.2 Test Equipment

Two pieces of external test equipment are required and will be provided by PL and SRI for the performance of these tests:

- The TPM Ground Support Equipment (GSE) system for operation of the TPM independently of APEX power and telemetry
- A self-contained E-field stimulus for excitation of the TPM E-field sensors.

2.1.3 Description of E-field Stimulus

Figure 2 shows an electrical schematic, and the approximate dimensions and physical shape of the hand-held E-field stimulus device. In operation, the stimulus head is placed against the spacecraft surface (with dielectric spacers as described below) at a selected location. The safety switch (for the prevention of unnecessary battery drain) is closed to provide a low-level current (through the high-resistance wire and safety resistors) to charge the plates in the head to 600 V. The magnetically activated switch is then mechanically triggered to cause the static E-field within the stimulus head to collapse rapidly. The collapsing field radiates a step E-field transient that originates at the stimulus location, propagates along the spacecraft surface and excites the TPM E-field sensors. The high-resistance leads and internal resistors provide dc isolation and electromagnetically decouple the operator and batteries from the stimulus head during device operation. The E-field stimulus has been designed to be easily cleaned before transport into the clean-room area.

The magnitudes of the E-fields generated on the spacecraft surface are related to the spacing between the stimulus head and the underlying conductive spacecraft ground plane. They are highest when the head is in direct contact with the ground plane surface. In order to compensate for the variations in spacing that result from differences in surface properties at the selected test points, the tests will be conducted both with and without a 0.375 in. thick × 3.5 in. diameter Delrin dielectric spacer installed on the face of the stimulus head. In both of these configurations, an additional thin dielectric sheet (of acceptable clean-room material, e.g., clean-room cloth or writing paper) will be placed between the head and the selected test point to further reduce the possibility of damage or contamination to delicate spacecraft or solar array surfaces.

The measured radiated E-fields from this device, when operated in direct electrical contact with a ground plane of dimensions similar to those of the APEX deployed panel and payload shelf, are approximately 80 V/m at a distance of 10 in. from the stimulus, but are reduced to less

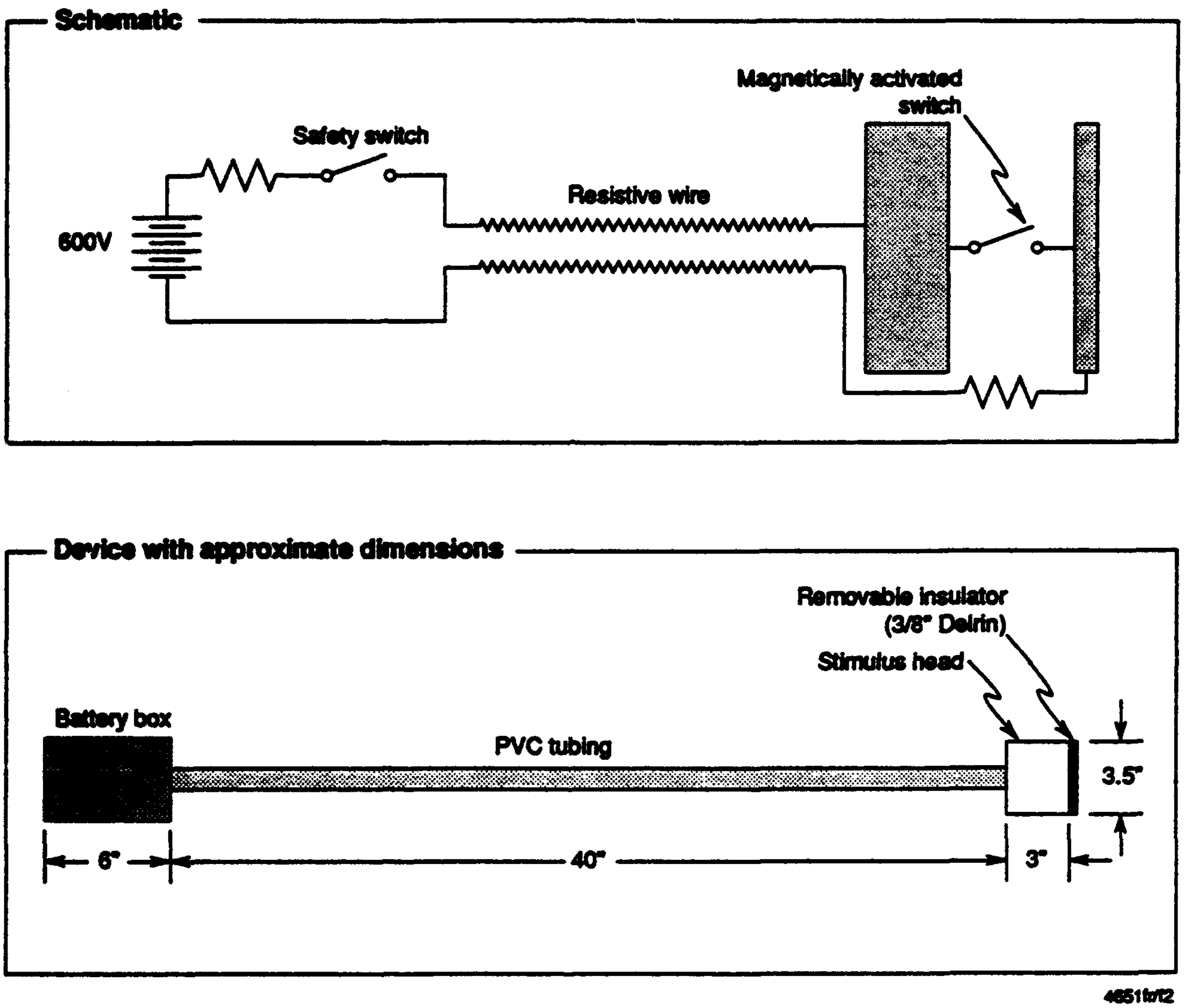

Figure 2. ELECTRIC FIELD STIMULUS

than 10 V/m in the volume behind the ground plane. The internal APEX payload module will therefore be exposed to an absolute maximum E-field level no greater than 10 V/m during the planned tests.

2.1.4 Required APEX Spacecraft Configuration

For the performance of these tests, ideally, all four deployable (solar array and payload) panels should be deployed to allow for the excitation of all major spacecraft electromagnetic resonances. However, if it is not practical to deploy all four panels, then, if at all possible, both the payload panel and the opposing solar array panel should be deployed.

All instruments (including the Langmuir probe and magnetometer booms) and cables on the payload panel and payload shelf should be as close as possible to the flight configuration. All electrically conductive protective covers should be removed from the deployed payload panel and payload shelf instruments. If possible, all other protective covers should be removed from the deployed solar panels and payload-shelf test arrays.

2.1.5 Test Procedure

The test point locations for application of the E-field stimulus for points both on the solar arrays and on the ground plane between them are shown in Figures 3 and 4, respectively. It is planned that a total of four series of tests will be performed:

- Series 1 - Solar Array Test Points without removable insulator
- Series 2 - Ground Plane Test Points without removable insulator
- Series 3 - Solar Array Test Points with removable insulator
- Series 4 - Ground Plane Test Points with removable insulator.

Before the start of the tests, the controller will be turned on and a functional check of the TPM will be performed. Before each series of tests, the TPM will be commanded on and data collection will commence. At that time, the E-field stimulus operator will:

- Position the stimulus at the first test point of the series
- Notify the GSE operator that he is "ready on test point #n"
- (The GSE operator will record the test point # and GSE system time)
- Trigger the E-field stimulus two times, approximately 5 seconds apart
- Move to the next test point, and repeat the sequence from Step 2 until all test points have been covered.

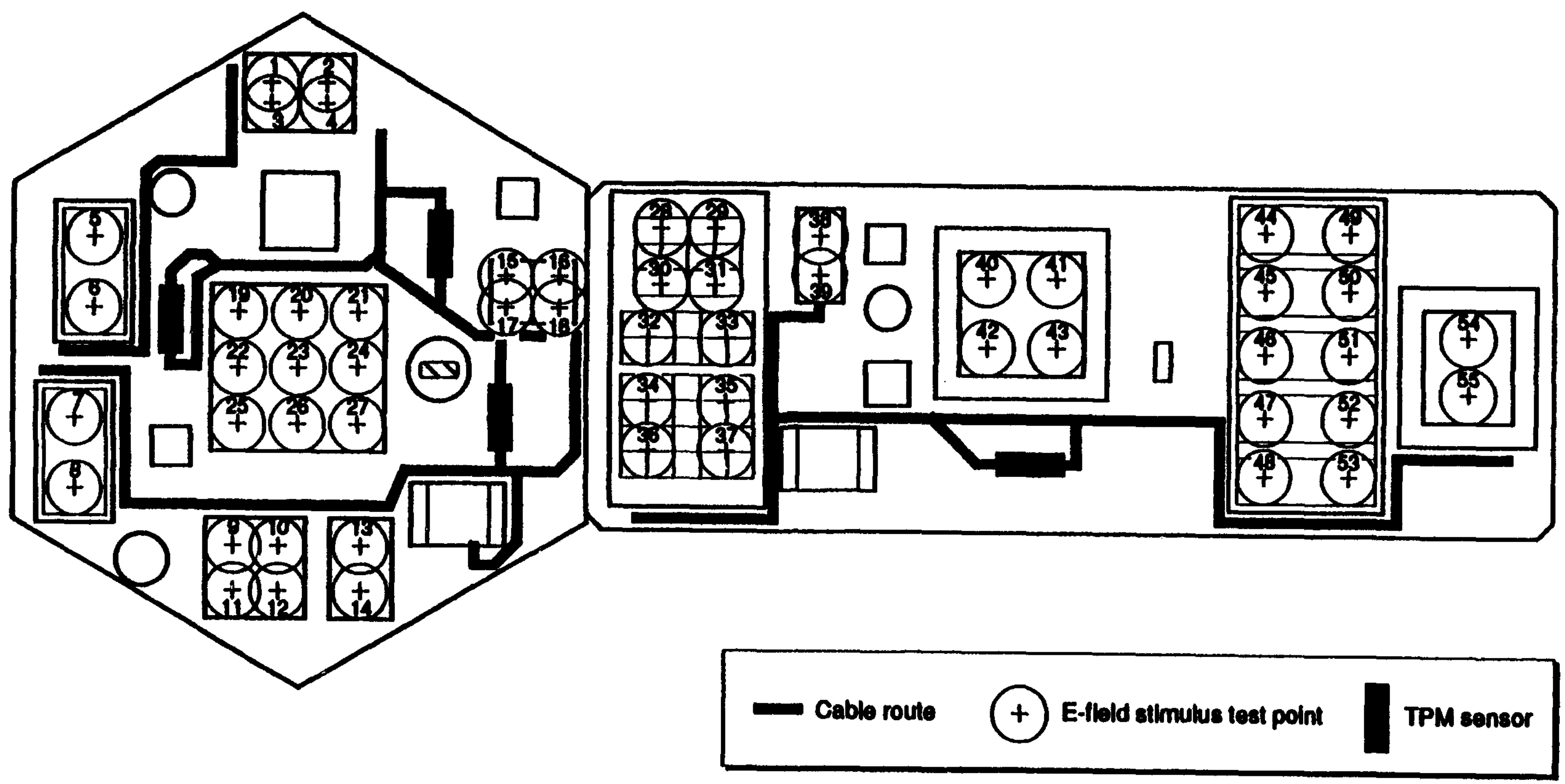

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Figure 3. SOLAR ARRAY TEST POINTS

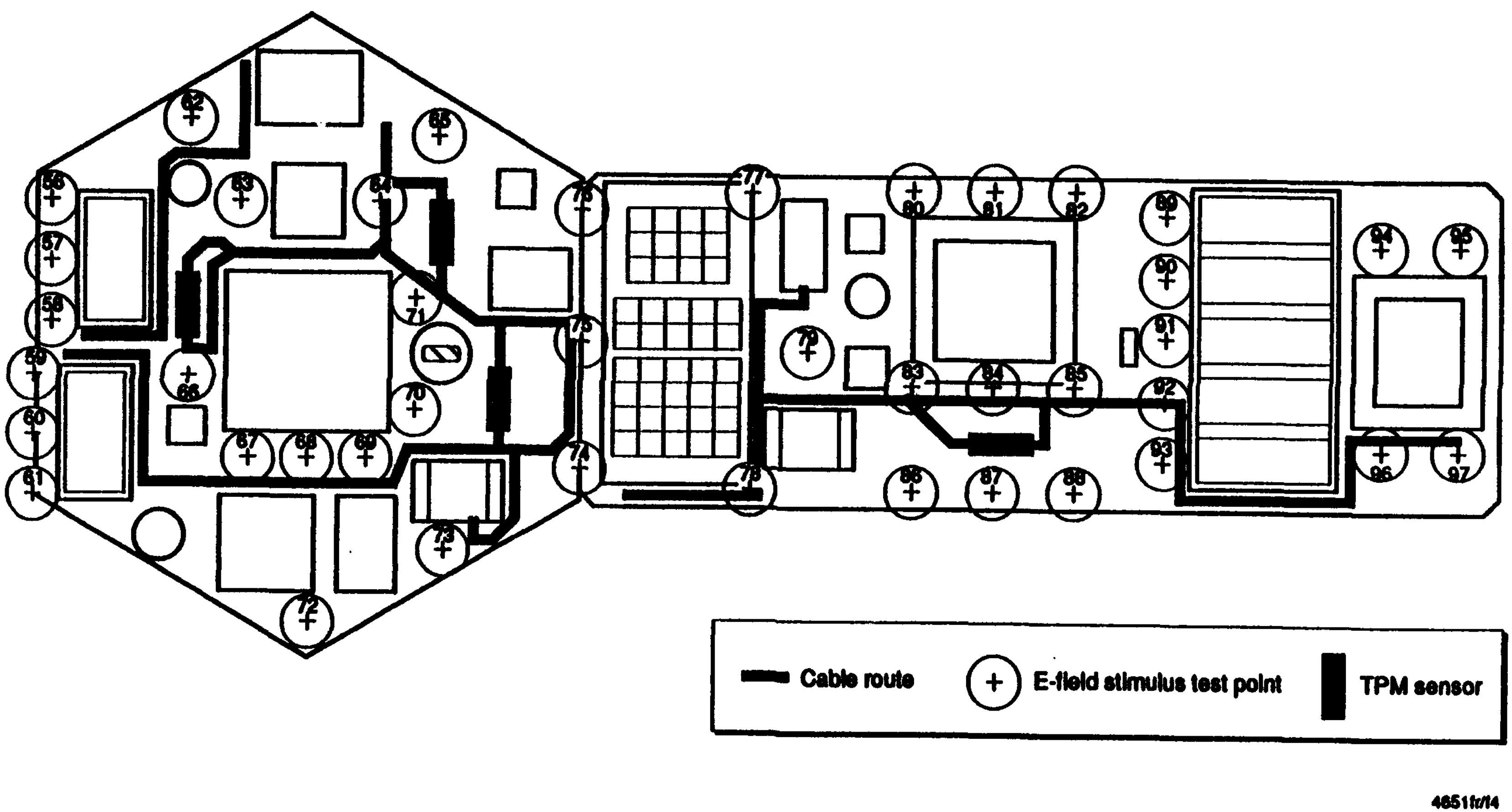

Figure 4. GROUND PLANE TEST POINTS

2.2 TEST PERFORMANCE AND TEST RESULTS

The Series 1 and 2 preflight TPM characterization tests (without the removable insulating spacer) in accordance with the above test plan were successfully completed. However, initial tests using the removable insulating spacer (as suggested for Series 3 and 4) showed that the resulting reduced coupling to the spacecraft, and thereby to the TPM sensors, produced responses that were either below the minimum measurable signal levels or too small to be of value at most test locations. The Series 3 and 4 tests were therefore eliminated. The quality and quantity of the data obtained from the Series 1 and 2 characterization tests are good and sufficient for use during the flight-data analysis task.

One additional valuable series of tests was added to the test sequence at the suggestion of PL personnel. After the planned sequence of tests had been completed, the SRI personnel left the clean-room test area and the test source was then used to stimulate the spacecraft at a number of locations unknown to SRI. The subsequent analytical identification of these "unknown" test points is discussed below.

3. PREPARATIONS FOR FLIGHT-DATA PROCESSING

3.1 PRELIMINARY DATA CLEAN-UP AND PROCESSING MATRIX PREPARATION

The TPM characterization tests generated a considerable quantity of raw data (5 relevant TPM parameters × 4 relevant TPM channels × 97 test point locations × 5 to 6 stimulations for each test point). For the purpose of the preliminary analysis, this data array was reduced by hand to the single TPM response matrix of Table 1. To provide x-y position data (columns 5 and 6) for each test point (column 4), the reference coordinates (in arbitrary units) shown on Figure 5 were used. Using this coordinate system, the locations of the 4 TPM E-field sensors are:

- Sensor 1 - (TPM Channel 0) @ (-31.7, -43.9)
- Sensor 2 - (TPM Channel 1) @ (+2.35, -46.5)
- Sensor 4 - (TPM Channel 3) @ (-53.0, -37.9)
- Sensor 5 - (TPM Channel 4) @ (-35.7, -32.9).

(Note that the TPM channel numbers are always one less than the E-field sensor numbers.)

Table 1

TPM RESPONSE MATRIX

Hour	Min	Sec	Test	X	Y	PA0	NA0	PD0	ND0	INT0	CNT	PA1	NA1	PD1	NA1	INT1	CNT	PA3	NA3	PD3	ND3	INT3	CNT	PA4	NA4	PD4	ND4	INT4	CNT4
14	7	48	56	-62.5	-30.87	0	0	0	0	0	0	0	0	0	0	3	0	73	15	56	0	120	0	3	3	0	0	27	0
14	8	20	57	-62.5	-34.88	1	0	0	0	14	0	0	0	5	0	7	0	83	21	69	0	113	1	7	3	0	0	45	0
14	8	40	58	-62.5	-38.87	0	0	0	0	11	0	0	0	0	0	5	0	88	25	74	1	119	1	7	3	0	0	44	0
14	8	57	59	-63.5	-42.44	0	0	0	0	10	0	0	0	0	0	2	0	67	12	45	0	93	1	1	0	0	0	16	0
14	9	24	60	-63.5	-46.45	0	0	0	0	0	0	0	0	0	0	0	0	37	7	16	0	71	0	1	0	0	0	21	0
14	9	45	61	-63.5	-50.44	0	0	0	0	0	0	0	0	0	0	0	0	14	0	1	0	40	0	0	0	0	0	8	0
14	10	10	62	-52.94	-25.5	4	1	0	0	17	0	0	0	2	0	8	0	65	14	46	0	95	1	26	10	13	0	67	0
14	10	30	63	-49.45	-30.88	6	1	0	0	32	0	0	0	0	0	12	0	114	39	91	16	142	1	44	8	19	0	69	0
14	11	11	64	-39.95	-30.88	19	5	0	0	59	0	0	0	0	0	11	0	40	10	14	0	84	0	157	101	142	78	158	0
14	11	34	65	-35.94	-26.5	25	6	2	0	64	0	5	1	10	5	33	0	19	5	4	0	59	0	136	87	111	52	149	0
14	12	38	66	-51.95	-42.5	3	0	0	0	20	0	0	0	0	0	2	0	165	75	142	78	204	0	11	3	5	0	44	0
14	14	23	67	-48.8	-47.93	10	1	0	0	30	0	0	0	0	0	2	0	53	8	30	0	91	0	5	1	0	0	28	0
14	14	48	68	-44.8	-47.93	28	4	5	0	55	0	0	0	0	0	4	0	30	6	11	0	75	0	7	2	0	0	33	0
14	15	34	69	-40.8	-47.93	69	11	32	0	83	1	0	0	0	0	7	0	18	4	4	0	72	0	10	3	0	0	35	0
14	16	12	70	-37.45	-44.62	128	61	99	34	151	1	0	0	0	0	6	0	7	2	0	0	30	0	16	6	2	0	53	0
14	16	49	71	-37.45	-37.18	51	9	23	0	70	0	0	0	0	0	7	0	15	4	4	0	57	0	154	95	143	80	150	0
14	17	13	72	-44.68	-58.86	17	3	2	0	52	0	0	0	12	3	13	0	7	1	0	0	36	0	2	1	0	0	22	0
14	17	37	73	-35.44	-54	90	31	47	1	105	1	7	2	26	13	40	0	10	3	0	0	52	0	13	6	0	0	60	0
14	18	2	74	-26.18	-48.43	137	73	99	34	152	1	15	5	14	7	60	0	2	0	0	0	22	0	21	8	0	0	65	0
14	18	38	75	-26.18	-39.89	127	59	97	31	140	1	6	1	4	0	33	0	0	0	0	0	10	0	62	14	36	0	77	0
14	19	4	76	-26.18	-31.21	38	7	13	0	66	0	5	1	4	2	35	0	1	0	0	0	19	0	90	32	77	3	111	0
14	19	59	77	-14.68	-30.01	10	3	3	0	43	0	21	7	25	10	63	0	0	0	0	0	10	0	16	6	2	0	62	0
14	20	39	78	-14.68	-49.69	21	2	3	0	48	0	68	9	56	15	87	1	0	0	0	0	6	0	3	1	0	0	22	0
14	21	7	79	-10.9	-40.5	21	5	12	6	56	0	56	12	38	27	94	0	0	0	1	0	10	0	11	4	1	0	48	0
14	21	36	80	-3.69	-29.78	3	0	2	0	16	0	47	8	35	8	102	0	0	0	0	0	6	0	4	1	0	0	25	0
14	22	2	81	1.76	-29.78	4	0	0	0	22	0	59	14	43	15	85	1	0	0	0	0	6	0	5	2	0	0	35	0
14	22	23	82	7.21	-29.78	1	0	0	0	18	0	56	15	39	15	85	0	0	0	0	0	6	0	2	1	0	0	27	0
14	23	10	83	-3.69	-42.78	46	55	110	92	15	0	139	55	170	126	142	1	3	4	98	87	0	0	21	20	92	89	11	0
14	23	35	84	1.76	-42.78	2	0	69	49	7	0	70	148	103	88	217	1	0	0	41	24	0	0	0	0	28	21	6	0
14	24	15	85	7.21	-42.78	0	0	22	9	11	0	150	78	145	73	168	1	0	0	5	0	0	0	0	0	4	0	9	0
14	24	38	86	-3.69	-49.78	6	4	1	0	33	0	144	82	134	61	223	1	0	0	0	0	7	0	3	3	0	0	19	0

Table 1

TPM RESPONSE MATRIX (continued)

Hour	Min	Sec	Test	X	Y	PA0	NA0	PD0	ND0	INT0	CNT	PA1	NA1	PD1	NA1	INT1	CNT	PA3	NA3	PD3	ND3	INT3	CNT	PA4	NA4	PD4	ND4	INT4	CNT4
14	24	59	87	1.76	-49.78	3	0	5	0	16	0	197	99	216	109	253	2	0	0	0	0	3	0	1	0	0	0	12	0
14	25	29	88	7.21	-49.78	2	0	4	2	19	0	150	83	141	65	168	1	0	0	0	0	0	0	0	0	0	0	0	0
14	26	1	89	13.27	-31.35	0	0	0	0	13	0	52	15	33	12	82	0	0	0	0	0	4	0	1	0	0	0	19	0
14	26	21	90	13.27	-35.52	0	0	0	0	13	0	72	24	47	7	99	1	0	0	0	0	3	0	0	0	0	0	16	0
14	26	50	91	13.27	-39.43	0	0	0	0	6	0	73	15	57	8	92	1	0	0	0	0	0	0	0	0	0	0	0	0
14	27	26	92	13.27	-43.67	0	0	0	0	3	0	80	21	75	8	101	1	0	0	0	0	0	0	0	0	0	0	0	0
14	27	54	93	13.14	-47.73	0	0	0	0	1	0	86	26	79	8	105	1	0	0	0	0	0	0	0	0	0	0	4	0
14	28	25	94	27.77	-33.28	0	0	0	0	4	0	16	6	8	1	58	0	0	0	0	0	0	0	0	0	0	0	0	0
14	29	3	95	33.05	-33.28	0	0	1	0	1	0	17	2	24	18	35	0	0	0	0	0	0	0	0	0	0	0	0	0
14	29	34	96	27.92	-46.88	0	0	0	0	2	0	23	7	24	8	61	0	0	0	0	0	0	0	0	0	0	0	0	0
14	30	8	97	33.05	-46.88	0	0	3	0	1	0	21	4	30	14	54	0	0	0	0	0	0	0	0	0	0	0	0	0
14	55	58	1	-46.65	-22.83	0	0	0	0	0	0	0	0	0	0	0	0	15	3	10	0	53	0	29	7	19	0	65	0
14	56	16	2	-43.11	-22.83	0	0	0	0	0	0	0	0	0	0	0	0	8	2	5	0	38	0	49	12	35	0	71	0
14	56	39	3	-46.65	-24.13	0	0	0	0	1	0	0	0	0	0	0	0	21	5	15	0	57	0	40	10	27	0	69	0
14	56	58	4	-43.11	-24.13	1	0	0	0	11	0	0	0	0	0	1	0	13	3	6	0	49	0	68	15	51	0	82	0
14	58	4	5	-58	-32.63	1	0	0	0	13	0	0	0	1	0	3	0	117	51	95	20	147	0	15	6	4	0	60	0
14	58	25	6	-58	-37.13	3	1	0	0	19	0	0	0	0	0	6	0	157	84	138	76	174	0	17	8	3	0	65	0
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14	59	5	8	-59.2	-48.63	0	0	0	0	1	0	0	0	0	0	0	0	36	10	9	0	76	0	2	0	0	0	20	0
14	59	25	9	-48.95	-52.23	23	6	0	0	63	0	0	0	0	0	12	0	50	12	13	0	88	0	12	5	0	0	58	0
15	0	8	10	-46.05	-52.23	33	9	3	0	67	0	0	0	0	0	14	0	41	11	9	0	82	0	14	6	0	0	60	0
15	0	26	11	-48.95	-55.13	19	5	0	0	60	0	0	0	0	0	10	0	31	8	2	0	69	0	10	4	0	0	51	0
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15	4	19	21	-40.95	-37.33	26	5	4	0	60	0	0	0	0	0	0	0	52	10	31	0	82	0	111	52	90	18	135	1
15	4	35	22	-48.65	-40.87	9	2	0	0	27	0	0	0	0	0	0	0	136	74	118	61	162	0	29	8	10	0	60	0
15	4	49	23	-44.8	-40.88	24	6	3	0	57	0	0	0	0	0	7	0	100	34	84	12	127	1	63	15	35	0	90	1
15	5	6	24	-40.95	-40.79	31	6	6	0	64	0	0	0	0	0	8	0	36	8	15	0	70	0	71	15	47	0	88	1
15	5	22	25	-48.65	-44.43	12	2	0	0	42	0	0	0	0	0	2	0	107	35	88	15	130	0	17	4	2	0	61	0
15	5	35	26	-44.8	-44.43	33	6	8	0	64	0	0	0	0	0	6	0	82	17	64	1	98	0	31	8	10	0	69	0

Table 1

TPM RESPONSE MATRIX (continued)

Hour	Min	Sec	Test	X	Y	PA0	NA0	PD0	ND0	INT0	CNT	PA1	NA1	PD1	NA1	INT1	CNT	PA3	NA3	PD3	ND3	INT3	CNT	PA4	NA4	PD4	ND4	INT4	CNT4
15	5	48	27	-40.95	-44.43	76	13	44	0	88	1	0	0	0	0	7	0	36	8	15	0	74	0	43	10	21	0	70	0
15	7	21	28	-21.43	-31.68	16	0	46	18	23	0	24	0	62	59	25	0	0	0	11	11	1	0	53	2	27	4	59	0
15	7	37	29	-17.93	-31.68	11	0	35	6	20	0	21	0	54	46	27	0	0	0	6	3	3	0	28	2	10	2	38	0
15	7	55	30	-21.43	-35.3	31	0	53	23	35	0	24	0	79	67	30	0	0	0	14	9	4	0	68	6	56	14	66	0
15	8	13	31	-17.93	-35.3	20	0	47	17	22	0	21	22	71	61	30	0	0	0	12	8	2	0	50	5	31	8	58	0
15	8	35	32	-22.21	-38.67	44	5	34	1	57	0	20	0	46	26	25	0	0	0	0	0	4	0	33	6	8	0	60	0
15	8	50	33	-17.21	-38.67	22	4	8	0	59	0	18	2	22	12	46	0	0	0	0	0	6	0	18	5	1	0	60	0
15	9	25	34	-22.21	-42.71	88	6	83	14	78	1	61	2	53	23	42	1	0	0	0	0	4	0	18	1	7	0	27	0
15	9	38	35	-17.21	-42.76	71	3	65	12	43	1	67	4	68	39	54	1	1	0	0	0	3	0	14	1	7	0	25	0
15	9	51	36	-22.21	-45.83	88	10	82	11	74	1	57	2	50	23	48	0	0	0	0	0	6	0	14	2	3	0	41	0
15	10	2	37	-17.21	-45.83	56	4	50	6	48	0	63	3	61	30	55	1	0	0	0	0	4	0	10	0	1	0	18	0
15	12	48	38	-11.19	-32.18	2	0	0	0	20	0	21	3	19	10	58	0	0	0	0	0	2	0	2	0	0	0	25	0
15	13	4	39	-11.19	-34.68	2	0	0	0	17	0	23	3	10	6	55	0	0	0	0	0	2	0	1	0	0	0	16	0
15	14	9	40	-0.43	-34.78	7	0	27	28	16	0	88	23	70	69	104	1	0	0	9	14	2	0	1	0	13	7	19	0
15	14	31	41	3.97	-34.78	7	0	40	35	12	0	91	26	79	74	105	1	0	0	16	15	1	0	0	0	16	11	14	0
15	14	49	42	-0.43	-39.18	8	0	23	22	17	0	110	50	90	65	141	1	0	0	8	11	2	0	1	0	16	8	16	0
15	15	12	43	3.97	-39.18	7	0	38	33	11	0	117	61	100	71	151	1	0	0	17	13	1	0	0	0	19	10	11	0
15	16	5	44	17.27	-31.68	0	0	0	0	5	0	28	8	21	4	65	0	0	0	0	0	0	0	0	0	0	0	7	0
15	17	12	45	17.27	-35.43	0	0	0	0	4	0	37	9	24	4	101	0	0	0	0	0	0	0	0	0	0	0	0	0
15	17	27	46	17.27	-39.43	0	0	0	0	5	0	52	12	32	3	78	0	0	0	0	0	0	0	0	0	0	0	5	0
15	17	41	47	17.27	-43.43	0	0	0	0	3	0	63	14	42	5	93	1	0	0	0	0	0	0	0	0	0	0	4	0
15	17	54	48	17.27	-47.18	0	0	0	0	4	0	67	14	50	8	89	1	0	0	0	0	0	0	0	0	0	0	5	0
15	18	11	49	22.77	-31.68	0	0	0	0	1	0	16	4	12	1	59	0	0	0	0	0	0	0	0	0	0	0	0	0
15	18	29	50	22.77	-35.43	0	0	0	0	1	0	20	6	10	0	62	0	0	0	0	0	0	0	0	0	0	0	4	0
15	18	41	51	22.77	-39.43	0	0	0	0	1	0	25	7	15	2	65	0	0	0	0	0	0	0	0	0	0	0	4	0
15	18	54	52	22.77	-43.43	0	0	0	0	0	0	28	8	18	3	66	0	0	0	0	0	0	0	0	0	0	0	0	0
15	19	7	53	22.77	-47.18	0	0	0	0	1	0	37	8	27	1	70	0	0	0	0	0	0	0	0	0	0	0	3	0
15	19	54	54	30.37	-38.28	0	0	25	15	1	0	13	1	64	56	32	0	0	0	10	6	0	0	0	0	3	0	0	0
15	20	23	55	30.37	-41.88	0	0	14	8	1	0	14	2	47	34	44	0	0	0	0	0	0	0	0	0	0	0	0	0

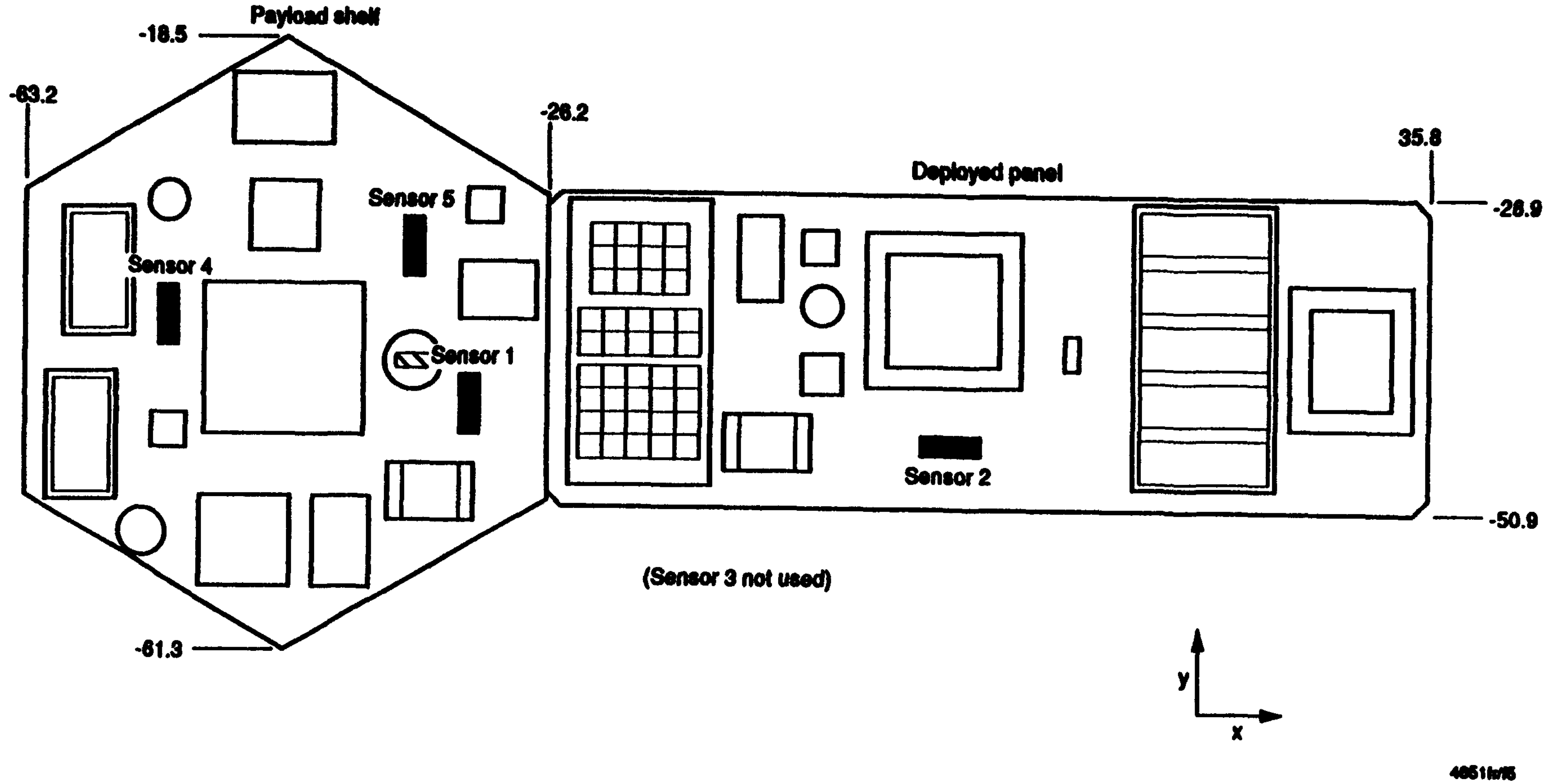

Figure 5. CALIBRATION DATA COORDINATE SYSTEM

The remaining columns show the TPM response data in 8-bit (0 to 255) telemetry units for the positive (PA) and negative (NA) peak amplitudes, the positive (PD) and negative (ND) maximum derivatives, the total integrals (INT), and pulse counts (CNT) for TPM channels 0, 1, 3, and 4.

The data shown in Table 1 were subsequently used for all calculations reported here. Prior to actual flight-data processing and analysis, some modifications and refinements of this data matrix will be performed, as discussed below.

3.2 PRELIMINARY DATA REVIEW

In order to gain insights into the physical significance of the TPM preflight calibration test results, the data in Table 1 were plotted as shown in Figures 6, 7, 8, and 9. In these figures the interpolated linear and shaded contours of the responses of each of the relevant sensor parameters are shown as a function of position of the test stimulus.

These plots illustrate the anticipated complexity of the vehicle excitation resulting from resonances, reflections, coupling through surface-mounted cables, and other related phenomena. An overlay of the peak amplitude plots does show that, for excitations of the type produced by the test stimulus, at least one sensor provides a response for each test location.

These plots are included here mainly to illustrate these phenomena, but they, or the results of other analyses of this type, may also provide useful insights if difficulties are encountered during the interpretation of actual flight data.

3.3 DATA PROCESSING ALGORITHM DEVELOPMENT AND IDENTIFICATION OF "UNKNOWN" TEST POINTS

A minimum least-squares error-analysis algorithm was used for processing the "unknown" data matrix to determine the "discharge" locations. A refined version of this technique, with enhancements of the type discussed below, will most likely be used for flight-data processing.

The basic least squares error technique involves subtracting each of a set of selected measured TPM parameters from each corresponding parameter in each of the rows of the characterization matrix (corresponding to possible discharge location signatures) and calculating the sums of the squares of these differences for each row. Each of these sums represents a measure of the error between the unknown signature and the characterization matrix signatures. By sorting these errors in ascending order, a list of the most likely location, second most likely, etc., is obtained.

a. Peak amplitude response

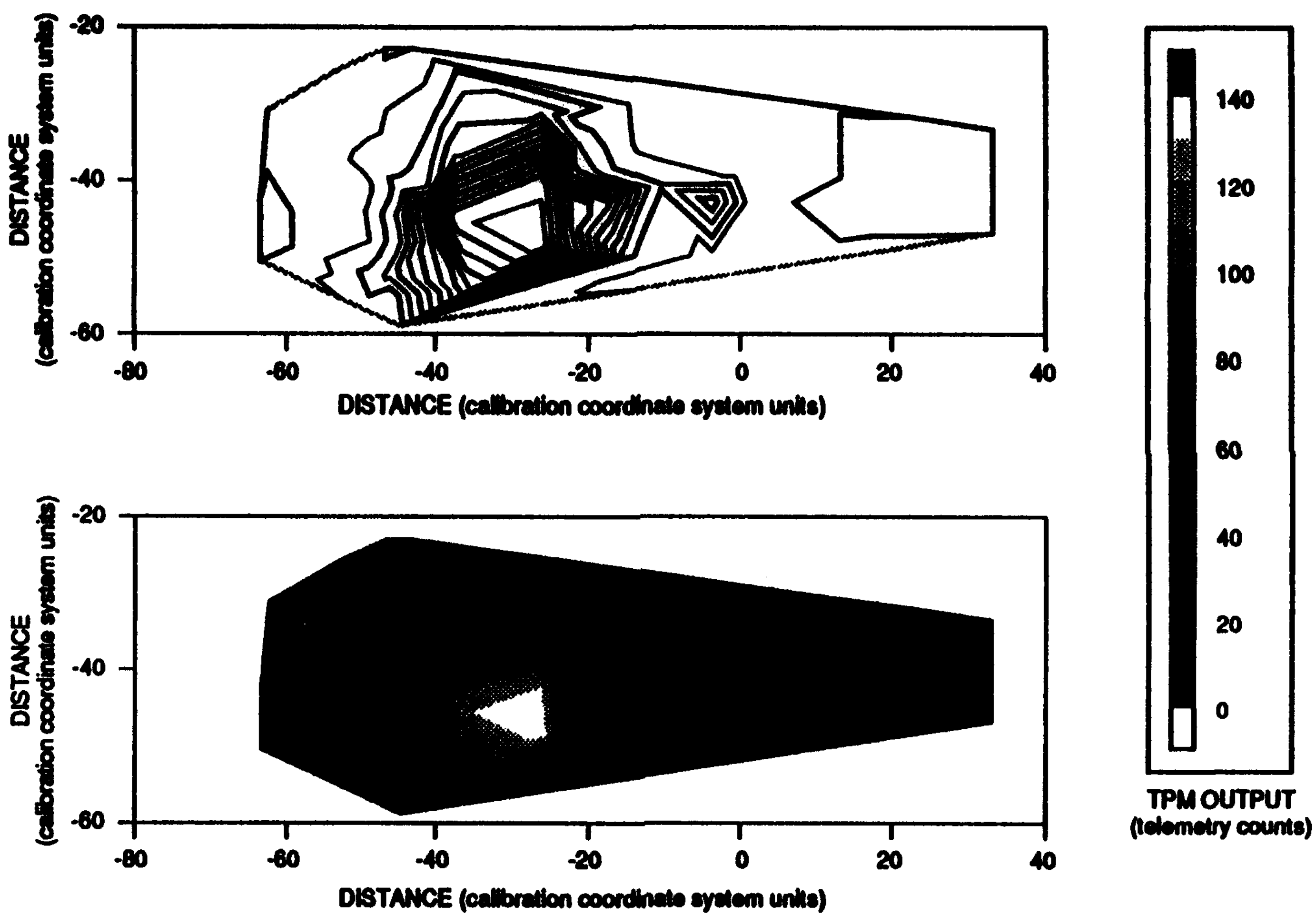

Figure 6. SENSOR 1 RESPONSE (continued on next page)

b. Peak derivative response

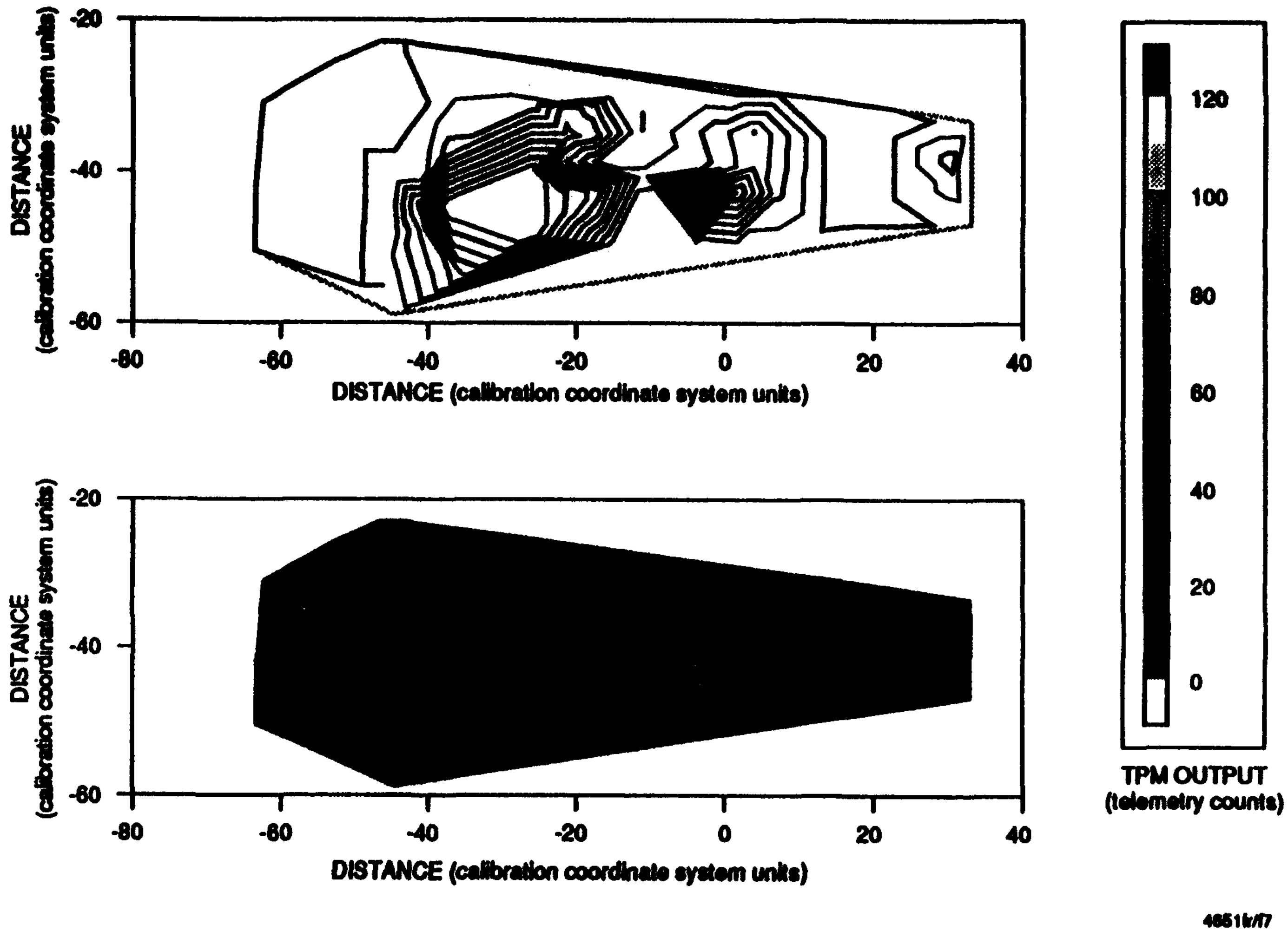

Figure 6. SENSOR 1 RESPONSE (continued on next page)

c. integral response

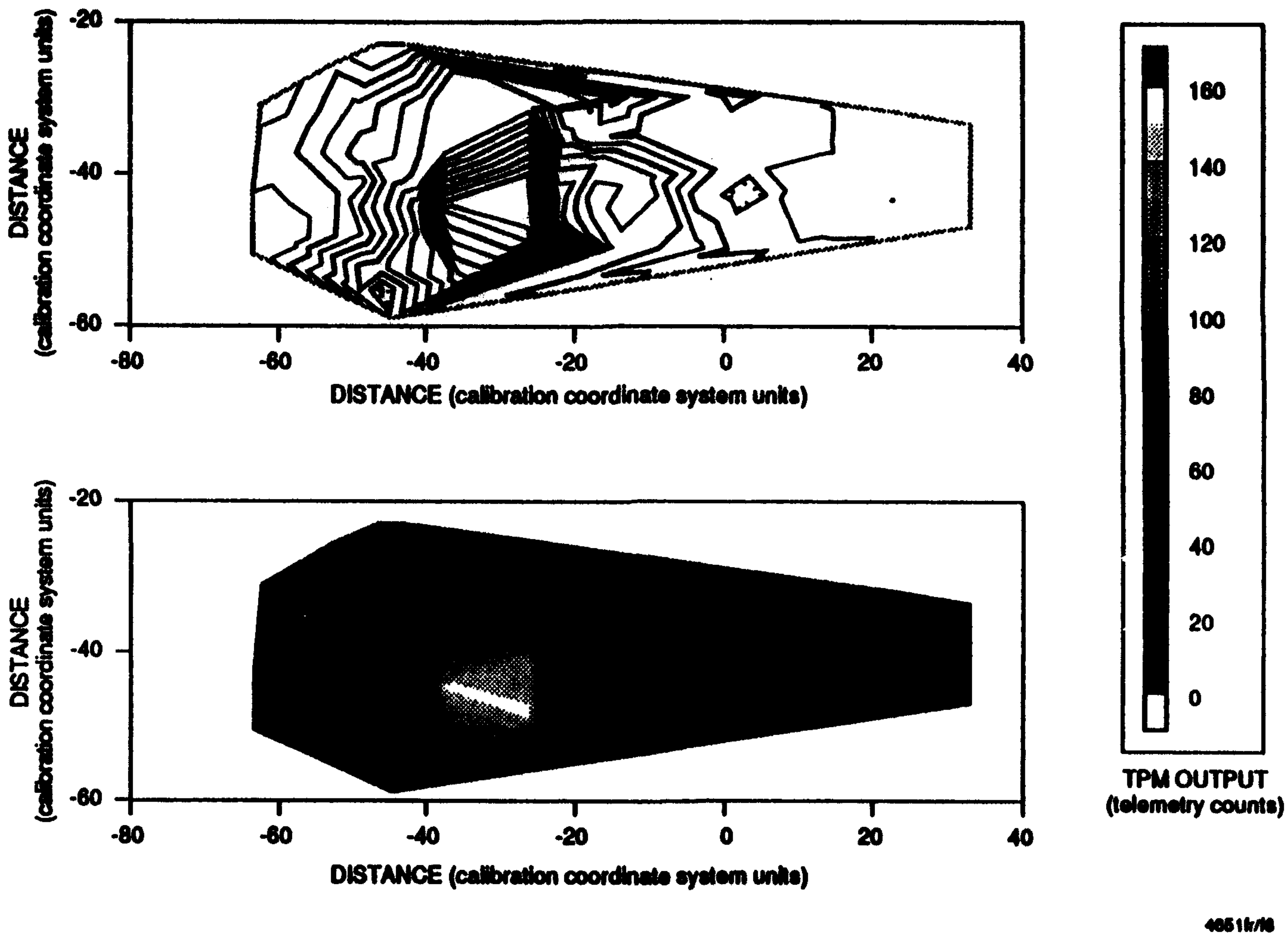

Figure 6. SENSOR 1 RESPONSE (concluded)

a. Peak amplitude response

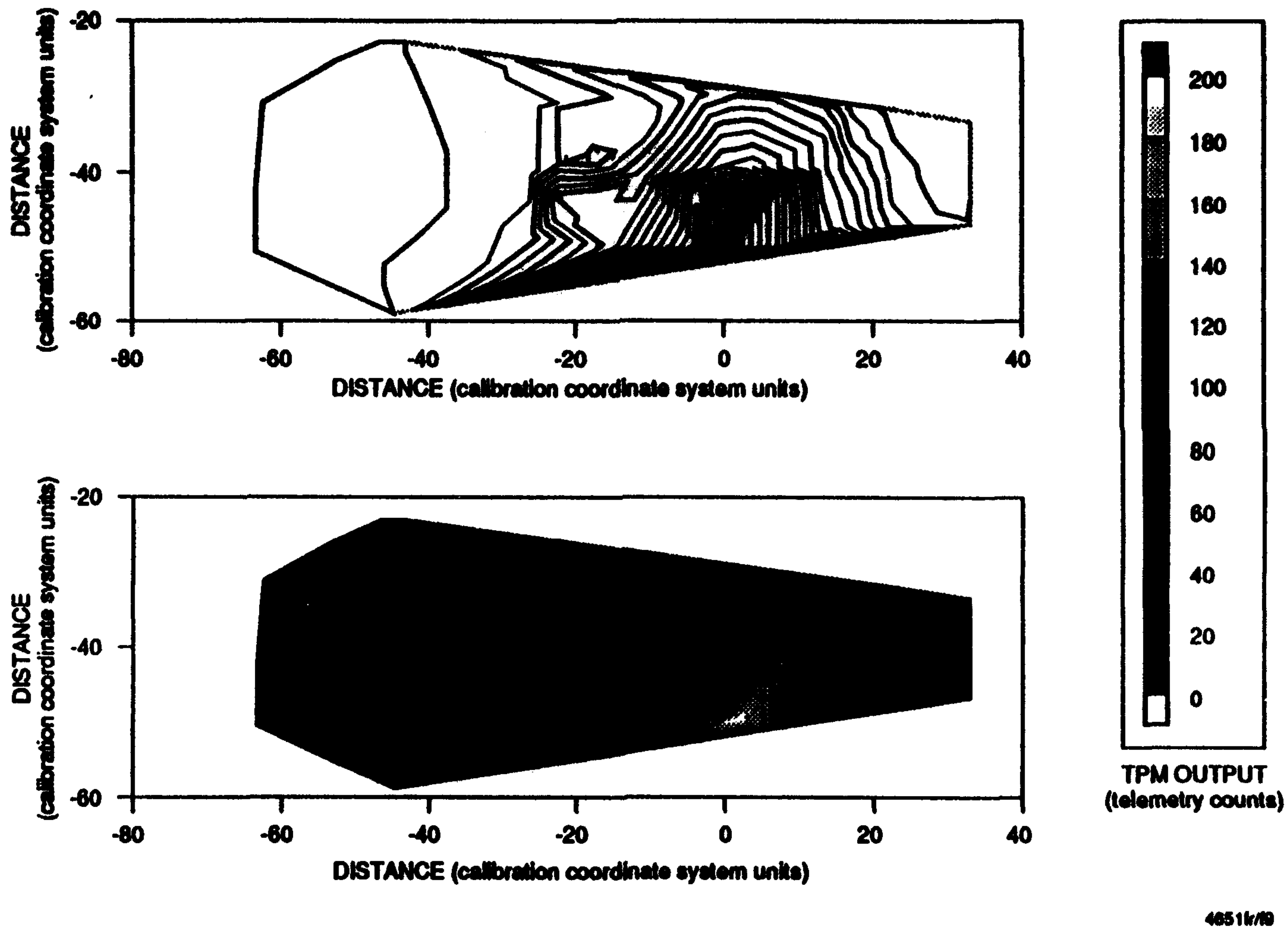

Figure 7. SENSOR 2 RESPONSE (continued on next page)

b. Peak derivative response

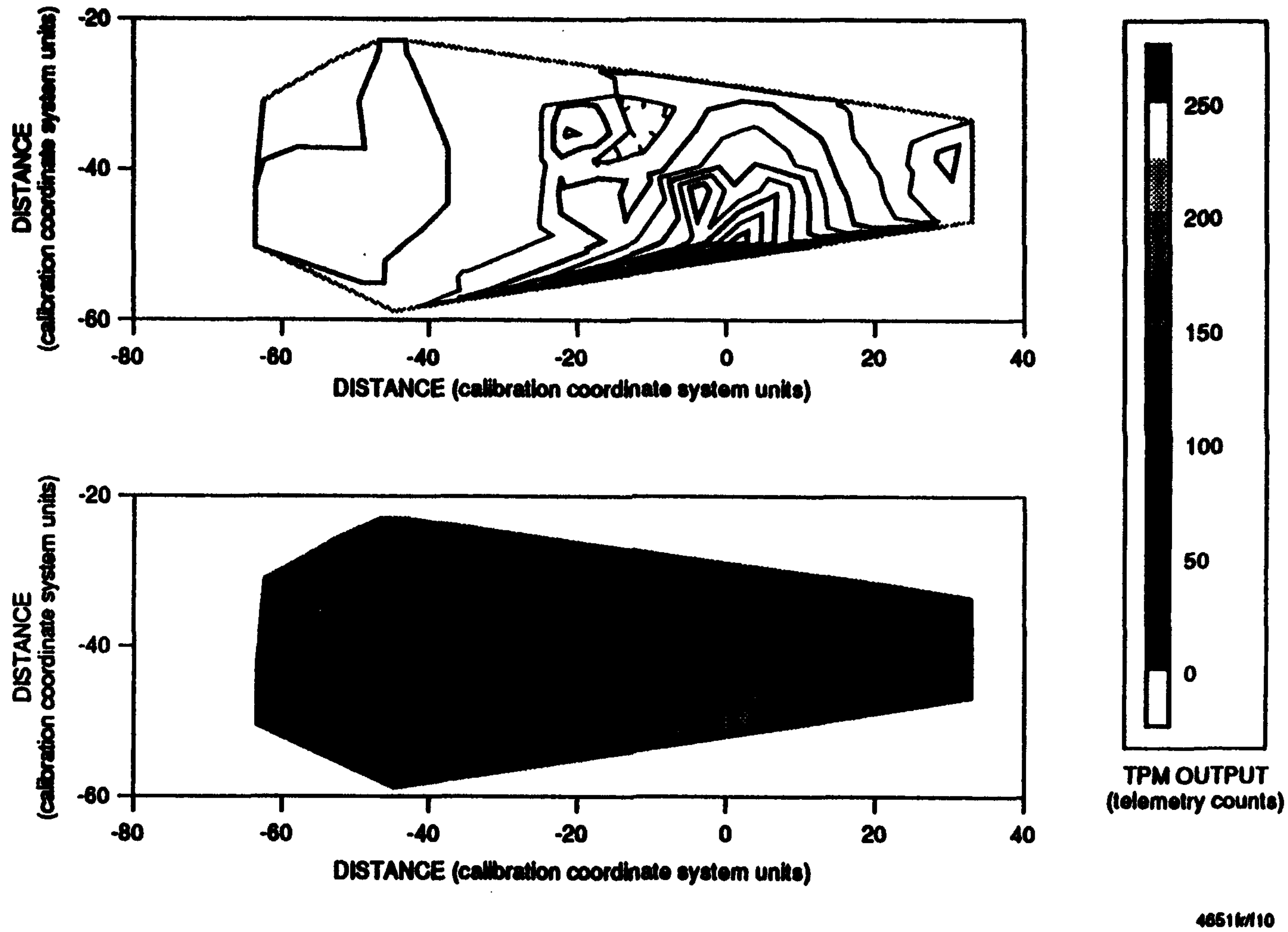

Figure 7. SENSOR 2 RESPONSE (continued on next page)

c. Integral response

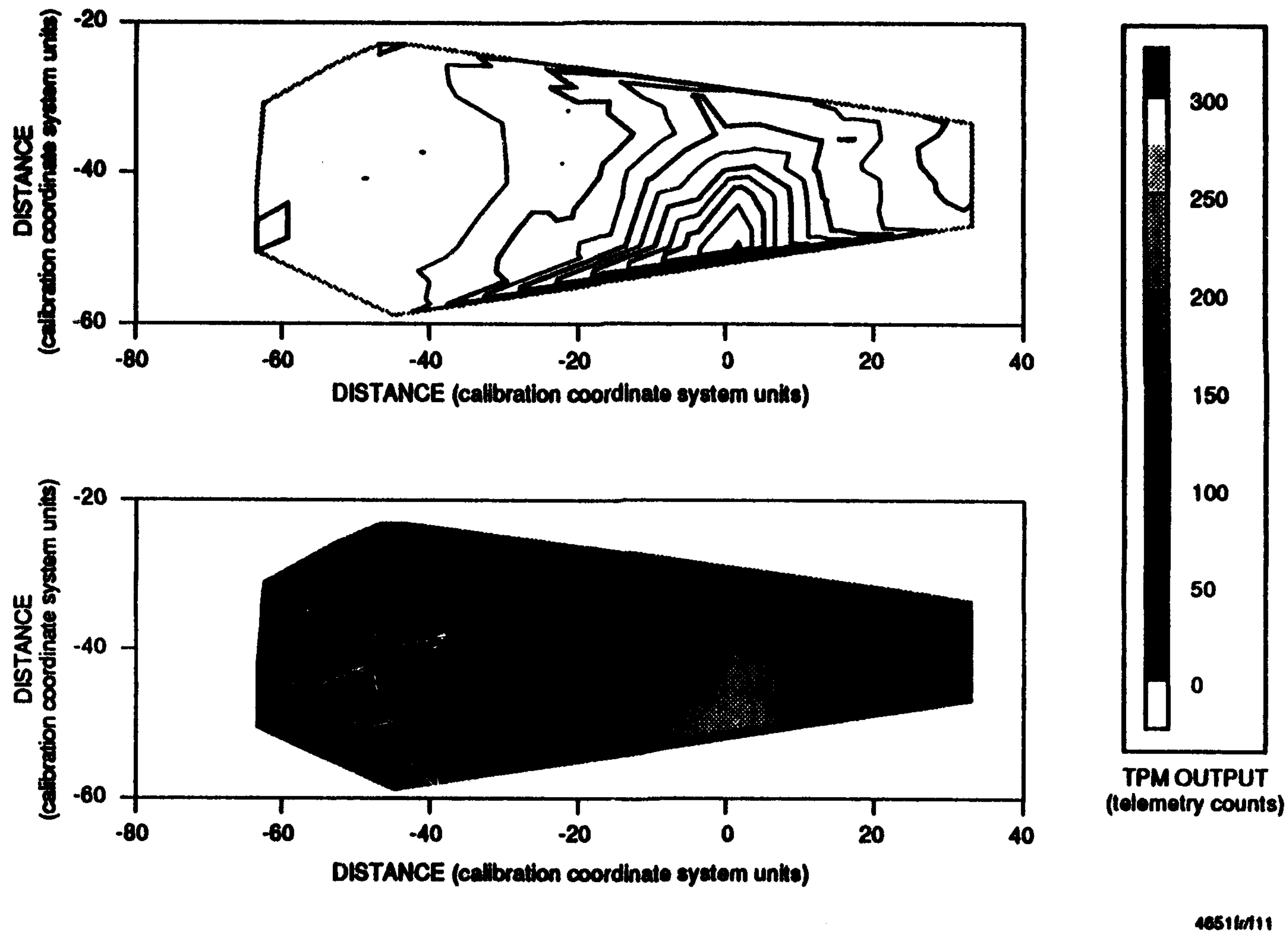

Figure 7. SENSOR 2 RESPONSE (concluded)

a. Peak amplitude response

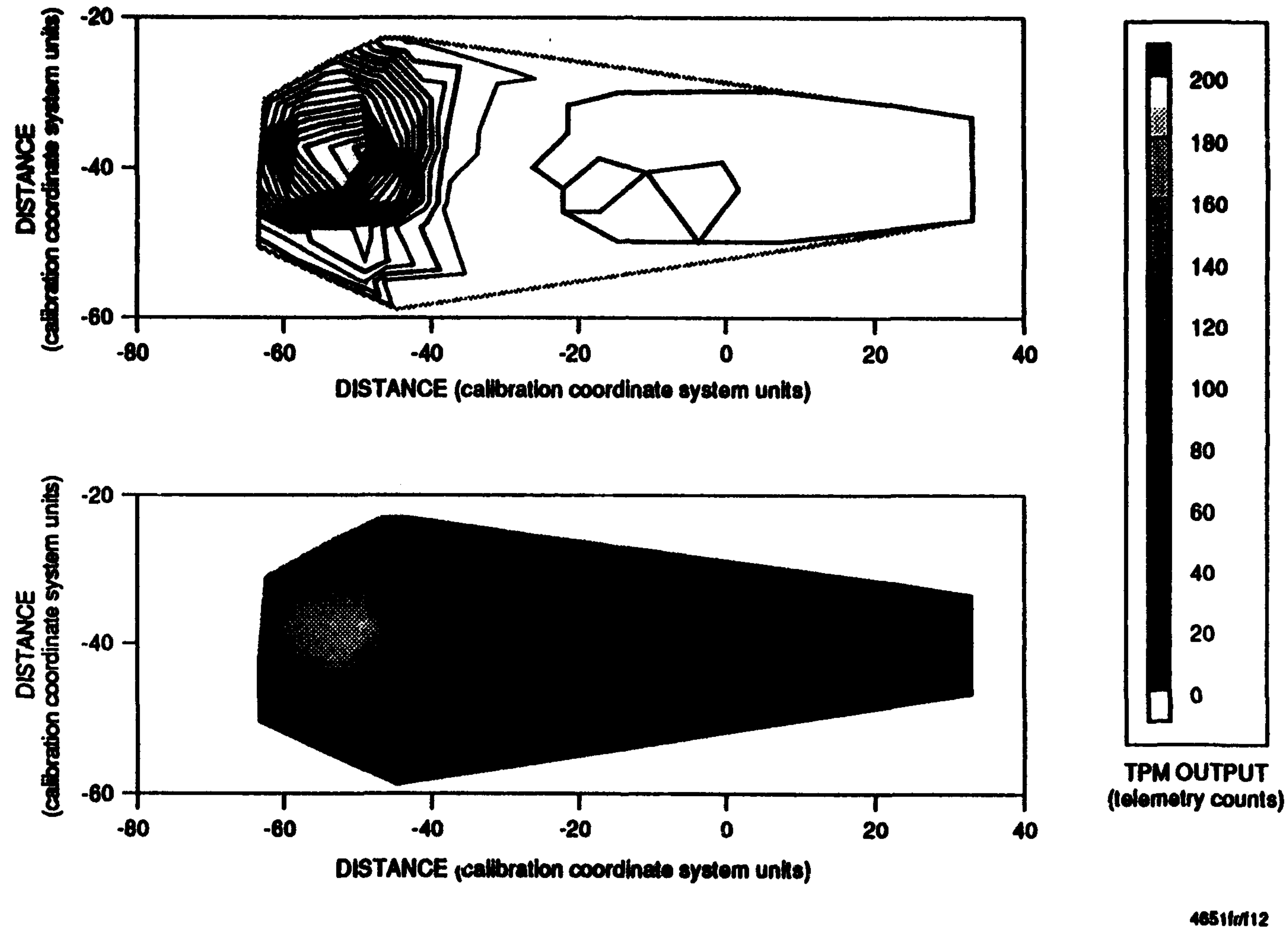

Figure 8. SENSOR 4 RESPONSE (continued on next page)

b. Peak derivative response

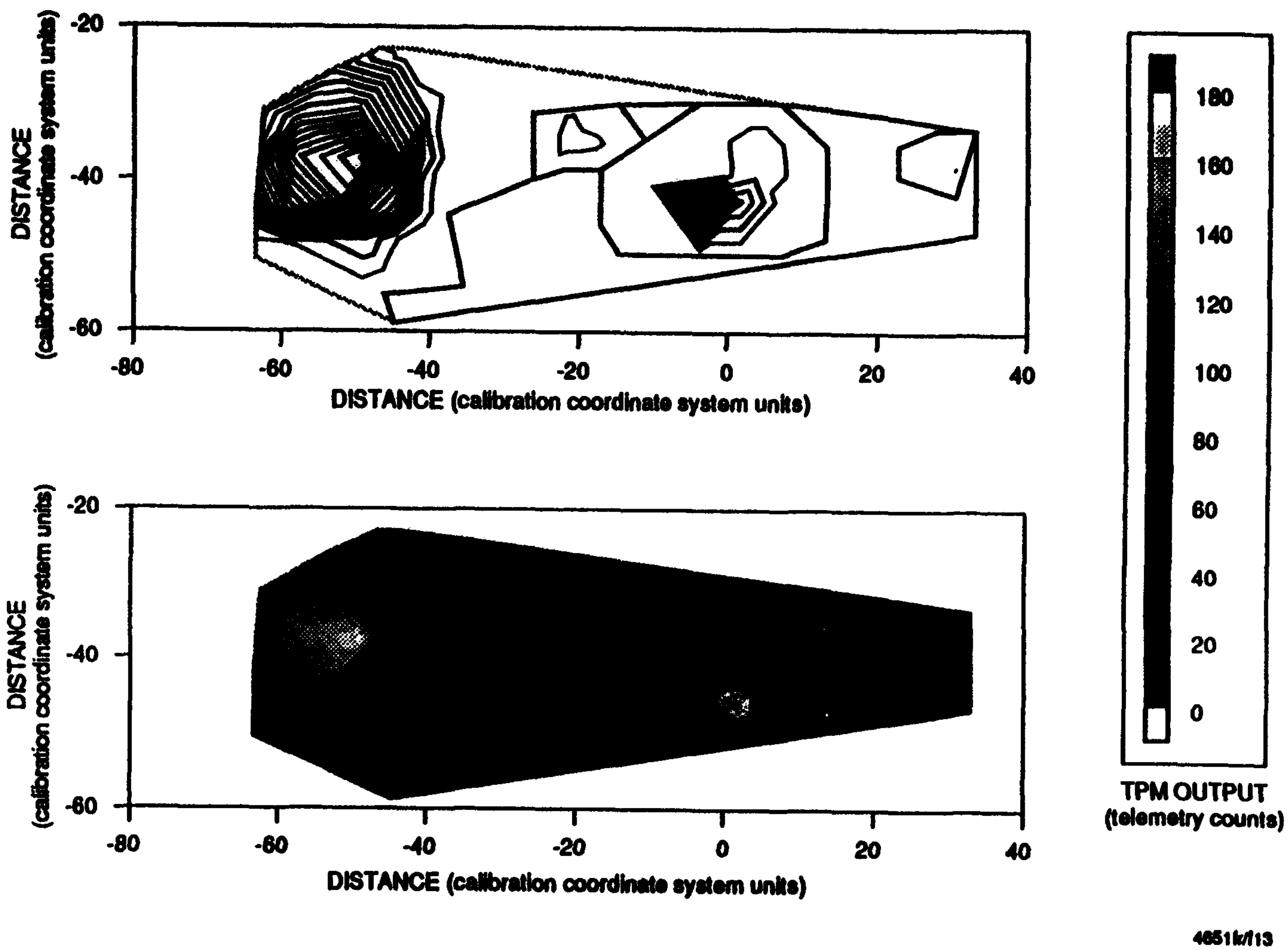

Figure 8. SENSOR 4 RESPONSE (continued on next page)

c. Integral response

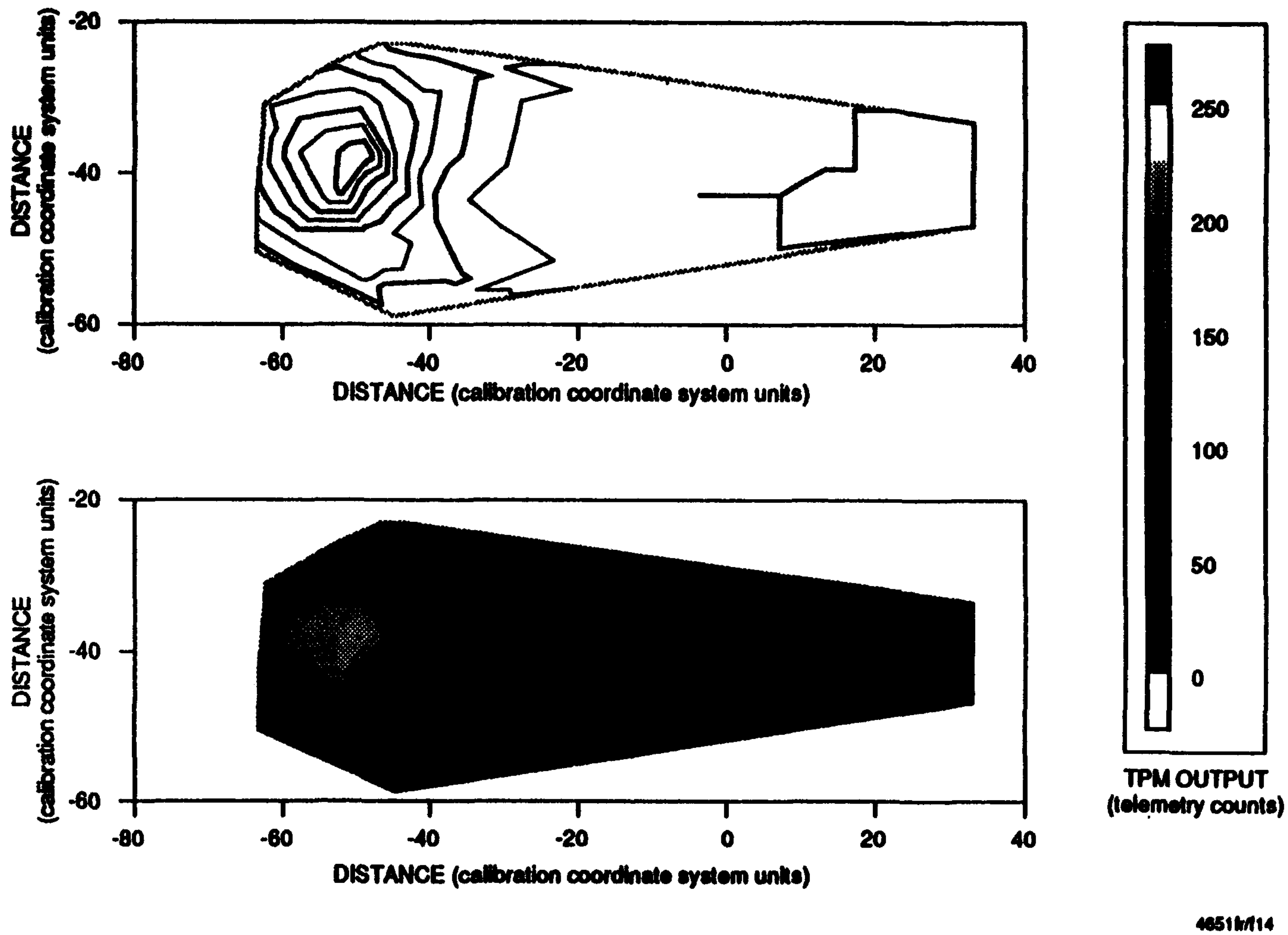

Figure 8. SENSOR 4 RESPONSE (concluded)

a. Peak amplitude response

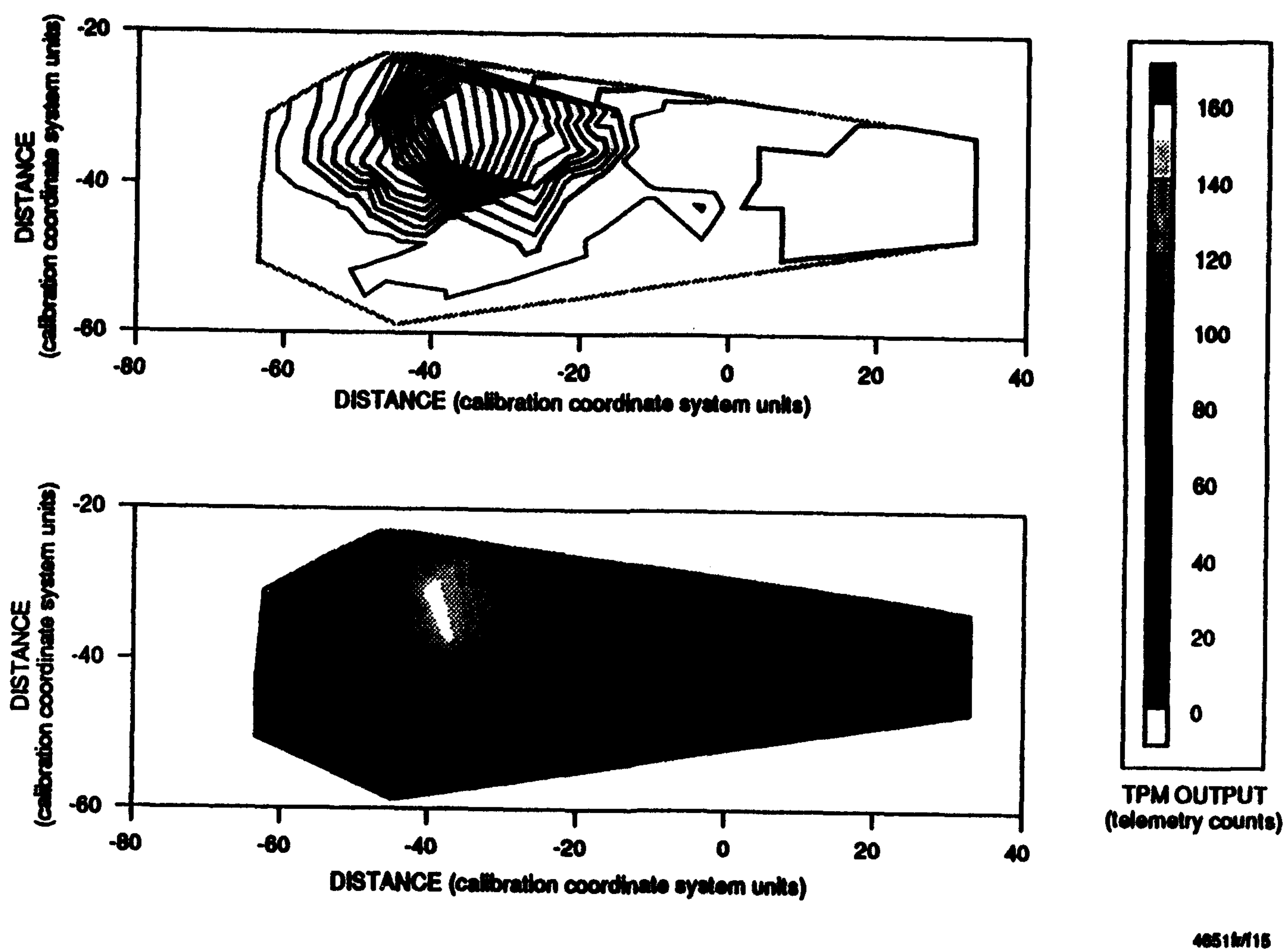

Figure 9. SENSOR 5 RESPONSE (continued on next page)

b. Peak derivative response

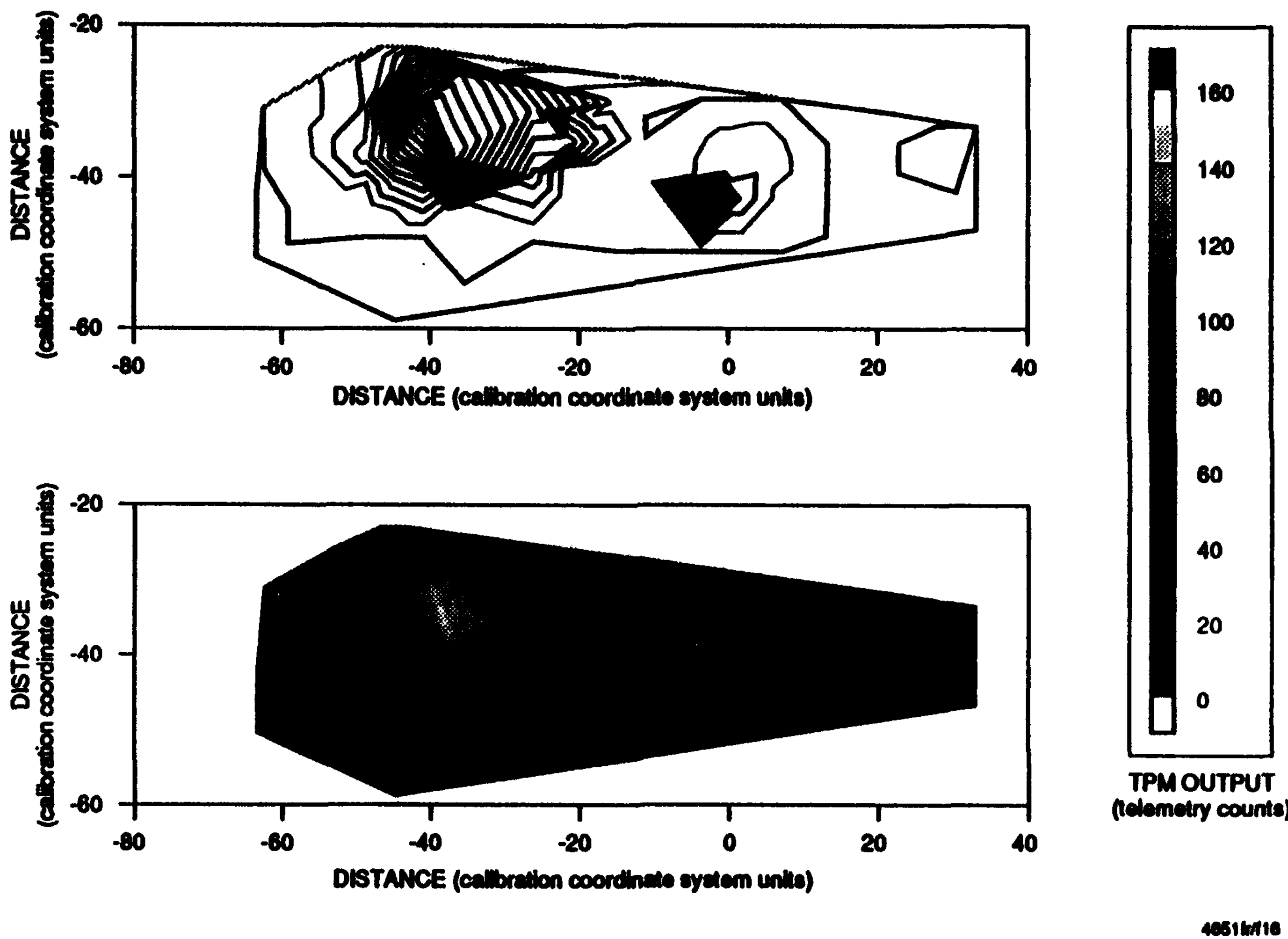

Figure 9. SENSOR 5 RESPONSE (continued on next page)

c. Amplitude response

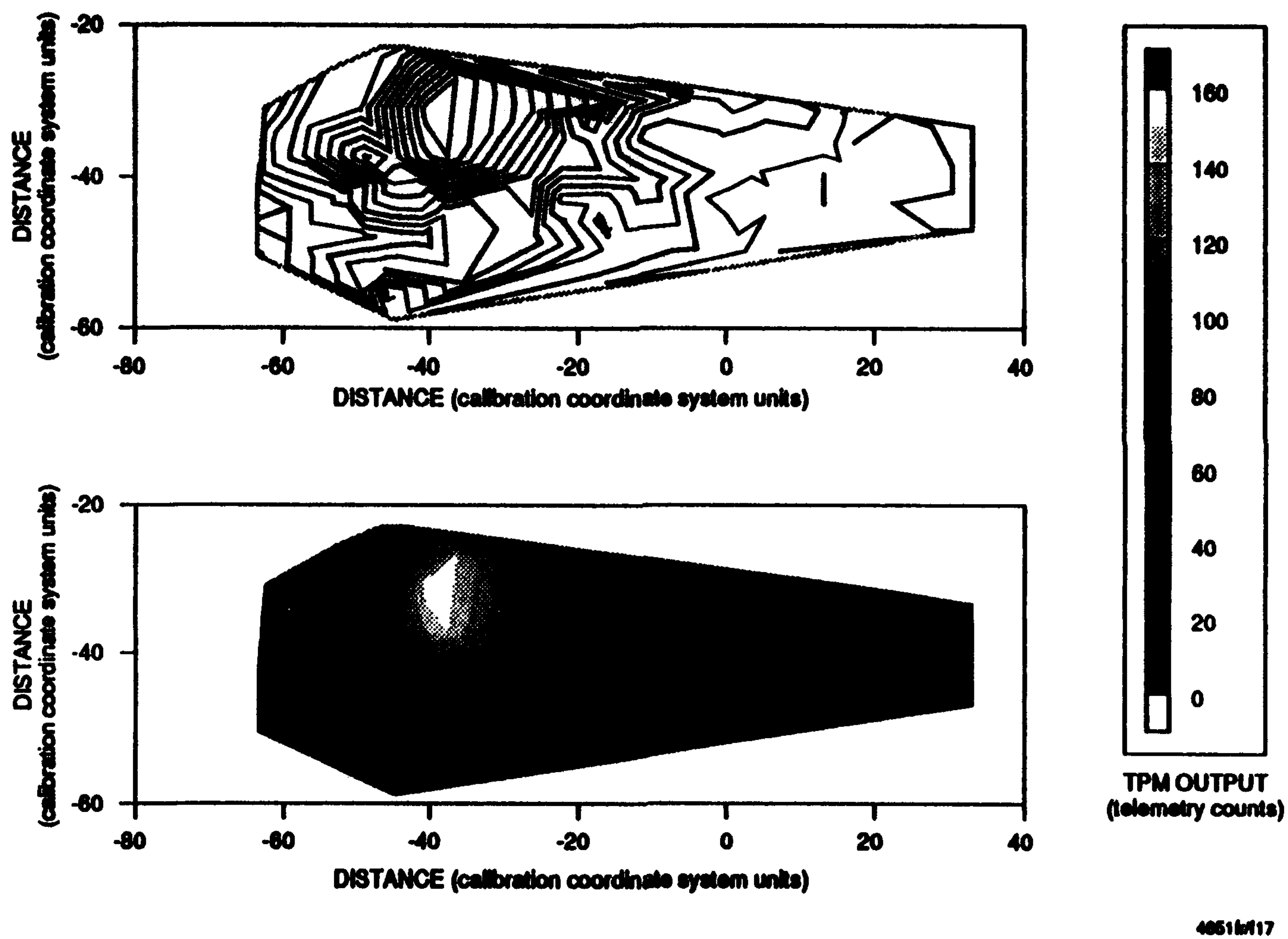

Figure 9. SENSOR 5 RESPONSE (concluded)

The results of applying this process to the "unknown" data obtained at the end of the preflight characterization test are illustrated in Table 2. Here selected measured parameters from the "unknown" data file were compared with the corresponding parameters from the characterization matrix in various combinations (i.e., All parameters, Amplitude parameters, Integral parameters, and Amplitude/Integral parameters).

Table 2 shows time as a reference to the original data file (Column 1), the minimum least squares error [Min LSE] (Column 2) corresponding to the numbered "discharge location" from Figures 3 and 4 selected as most likely [MLDL] (Column 3), the second lowest least-squares error [2nd LSE] (Column 4), the second most likely discharge location [2nd MLDL] (Column 5), and the next three possible discharge locations in descending order of likeliness.

On the basis of this analysis, our best present estimates of the "unknown" discharge locations would correspond to those derived from amplitude data alone shown in Column 3 of the second page of Table 2. The locations derived from amplitude data alone were chosen because, in this particular analysis, they show the least variation in selected location from one discharge in a series to another. It should also be noted that, at least for the first few highest-likelihood locations in each row, the selected locations are generally adjacent to one another.

4. FURTHER REFINEMENT OF DATA PROCESSING ALGORITHMS

The relatively simple analysis method illustrated above works well using essentially raw data because both the characterization data and the "unknown" data were obtained using the same electromagnetic stimulus. However, to deal more accurately with actual flight data, several improvements and refinements to the analysis procedure are planned. These include, but are not limited to, the following:

- Expansion and Normalization of the Characterization Matrix. Characterization data were obtained with the stimulus configured to produce E-field transients of positive polarity with respect to the spacecraft surface. To fill out the characterization matrix for negative polarity transients, the existing positive transient data will be converted to engineering units, and the corresponding expected responses for similar negative transients will be determined from the TPM calibration tables. This will provide a complimentary characterization matrix for processing of predominantly negative transients.

Table 2
LEAST-SQUARES ERRORS [LSE] AND MOST LIKELY DISCHARGE LOCATIONS [MLDL] FOR DISCHARGES OCCURRING AT TIMES IN COLUMN 1

ALL PARAMETERS								
Time	Min LSE	MLDL	2nd Min LSE	2nd MLDL	3rd Min LSE	3rd MLDL	4th Min LSE	4th MLDL
15:59:08	1146	27	2476	24	4887	10	6130	9
15:59:11	1117	27	3057	24	5234	10	6256	26
15:59:13	977	27	2821	24	4968	10	5842	26
15:59:15	1346	27	2866	24	4407	10	5309	69
15:59:17	1053	27	2733	24	5062	10	6160	69
15:59:34	2115	24	2131	27	3458	10	4186	26
15:59:36	2162	27	2190	24	3453	10	4151	26
15:59:38	2174	27	2214	24	3445	10	4015	26
15:59:40	2096	27	2413	10	2560	24	3168	9
16:00:20	632	12	955	72	965	11	1098	68
16:00:22	792	11	805	12	1013	68	1036	72
16:00:24	497	12	882	72	1188	11	1243	68
16:00:42	891	59	1059	57	1154	56	1203	62
16:00:43	970	59	1034	57	1098	62	1141	56
16:00:45	938	62	1110	57	1320	59	1539	56
16:00:47	580	59	899	56	1050	57	1428	67
16:00:49	881	62	1037	57	1383	59	1492	56
16:01:09	143	3	173	1	1054	2	2406	4
16:01:11	211	1	359	3	898	2	2750	4
16:01:13	150	1	174	3	1035	2	2513	4
16:01:15	141	3	167	1	1036	2	2414	4
16:01:17	161	3	195	1	1106	2	2444	4
16:01:35	218	20	1492	23	5193	63	8072	26
16:01:37	191	20	1479	23	5182	63	8161	26
16:01:39	1019	20	2335	23	5238	63	8625	26
16:01:41	181	20	1461	23	5216	63	8149	26
16:01:43	1256	20	3148	23	6519	63	11230	25
16:02:14	220	7	1045	58	1664	57	2466	5
16:02:16	198	7	919	58	1564	57	2266	5
16:02:18	181	7	962	58	1609	57	2363	5
16:02:20	153	7	1056	58	1697	57	2488	56
16:02:22	260	7	975	58	1644	57	2082	5
16:02:56	227	89	325	47	329	82	340	48
16:02:58	278	46	344	47	388	89	427	48
16:03:00	233	47	406	48	435	89	457	80
16:03:02	204	89	282	82	318	47	355	48
16:03:04	204	89	282	82	318	47	355	48
16:03:31	2152	33	3158	77	3467	79	5449	78
16:03:33	1353	33	2065	77	3214	79	4611	32
16:03:35	1658	33	2366	77	2969	79	5268	32
16:03:37	1326	33	2044	77	3209	79	4582	32

Table 2

LEAST-SQUARES ERRORS [LSE] AND MOST LIKELY DISCHARGE LOCATIONS [MLDL] FOR DISCHARGES OCCURRING AT TIMES IN COLUMN 1 (continued)

16:03:38	1458	33	2254	77	3305	79	4480	32
16:04:14	1772	77	2066	33	4075	79	4902	32
16:04:16	533	33	583	77	3688	38	4570	79
16:04:18	722	33	760	77	2879	38	3592	39
16:04:19	684	33	696	77	4391	79	4577	38
16:04:21	651	33	709	77	4458	38	4498	79
16:04:46	142	47	201	48	467	91	547	90
16:04:47	184	48	241	47	453	89	484	91
16:04:49	201	48	288	47	480	89	491	91
16:04:51	192	48	303	47	474	91	491	89
16:04:53	161	48	184	47	433	91	542	89
16:05:09	83	94	91	49	109	50	207	51
16:05:11	66	50	106	94	110	49	120	51
16:05:15	51	50	83	49	89	94	107	51
16:05:17	51	50	83	49	89	94	107	51
16:05:19	51	50	83	49	89	94	107	51
16:05:21	77	49	95	94	99	50	187	51
16:05:56	3752	54	6426	29	6880	55	8224	40
16:05:57	2640	54	4172	55	4884	29	6859	97
16:05:59	3137	54	5709	29	5719	55	8195	40
16:06:01	4290	54	6874	29	7594	55	8371	41
16:06:03	3032	54	5408	55	5570	29	7396	40
16:06:22	749	79	966	81	1204	82	1453	78
16:06:24	392	79	1741	81	1786	78	2281	82
16:06:26	370	79	1687	81	1766	78	2245	82
16:06:28	534	79	1165	81	1484	78	1513	82
16:06:29	814	79	897	81	1117	82	1370	78

Table 2
LEAST-SQUARES ERRORS [LSE] AND MOST LIKELY DISCHARGE LOCATIONS [MLDL] FOR DISCHARGES OCCURRING AT TIMES IN COLUMN 1 (continued)

AMPLITUDE PARAMETERS								
Time	Min LSE	MLDL	2nd Min LSE	2nd MLDL	3rd Min LSE	3rd MLDL	4th Min LSE	4th MLDL
15:59:08	434	27	1401	24	2617	10	2701	26
15:59:11	390	27	1413	24	2525	10	2725	26
15:59:13	365	27	1478	24	2586	10	2745	69
15:59:15	369	27	1448	24	2446	10	2669	69
15:59:17	411	27	1502	24	2824	10	2874	26
15:59:34	914	27	1025	24	1685	26	1793	10
15:59:36	945	27	1056	24	1624	26	1814	10
15:59:38	930	27	1097	24	1585	26	1741	10
15:59:40	850	27	1133	10	1229	24	1625	26
16:00:20	97	12	145	72	155	61	285	11
16:00:22	117	12	155	72	185	61	243	11
16:00:24	97	12	145	72	155	61	285	11
16:00:42	41	56	53	59	198	57	356	62
16:00:43	65	56	85	59	206	57	288	62
16:00:45	50	56	106	59	131	57	265	58
16:00:47	45	56	73	59	174	57	328	58
16:00:49	50	56	106	59	131	57	265	58
16:01:09	26	3	61	1	340	2	1011	29
16:01:11	37	3	50	1	369	2	998	29
16:01:13	37	3	50	1	369	2	998	29
16:01:15	37	3	50	1	369	2	998	29
16:01:17	26	3	61	1	340	2	1011	29
16:01:35	14	20	381	23	1530	63	2960	26
16:01:37	14	20	381	23	1530	63	2960	26
16:01:39	74	20	313	23	1358	63	2546	26
16:01:41	14	20	381	23	1530	63	2960	26
16:01:43	54	20	329	23	1384	63	2662	26
16:02:14	13	7	281	58	323	5	358	25
16:02:16	5	7	265	58	291	5	322	25
16:02:18	4	7	272	58	314	5	349	25
16:02:20	1	7	241	58	341	5	356	25
16:02:22	10	7	266	5	298	58	317	25
16:02:56	1	47	9	48	40	84	64	90
16:02:58	0	47	16	48	53	84	54	82
16:03:00	9	47	21	82	42	81	49	48
16:03:02	0	47	16	48	53	84	54	82
16:03:04	0	47	16	48	53	84	54	82
16:03:31	523	32	598	33	1169	77	1214	79
16:03:33	465	32	560	33	1109	77	1126	79
16:03:35	419	33	558	32	902	77	1109	29
16:03:37	486	32	585	33	1075	79	1128	77

Table 2
LEAST-SQUARES ERRORS [LSE] AND MOST LIKELY DISCHARGE LOCATIONS [MLDL] FOR DISCHARGES OCCURRING AT TIMES IN COLUMN 1 (continued)

16:03:38	483	32	714	33	1161	37	1210	79
16:04:14	57	33	91	29	154	77	706	31
16:04:16	52	33	74	29	137	77	689	31
16:04:18	53	33	81	29	144	77	696	31
16:04:19	59	33	83	29	172	77	636	31
16:04:21	45	33	89	29	154	77	686	31
16:04:46	1	47	25	48	41	82	50	81
16:04:47	4	47	4	48	29	84	49	90
16:04:49	4	47	4	48	29	84	49	90
16:04:51	4	47	4	48	29	84	49	90
16:04:53	0	47	16	48	53	84	54	82
16:05:09	1	95	4	94	4	49	4	50
16:05:11	1	95	4	94	4	49	4	50
16:05:15	1	95	4	94	4	49	4	50
16:05:17	1	95	4	94	4	49	4	50
16:05:19	1	95	4	94	4	49	4	50
16:05:21	1	95	4	94	4	49	4	50
16:05:56	2	81	23	82	49	47	75	89
16:05:57	2	81	35	82	51	47	91	48
16:05:59	0	81	27	82	57	47	81	89
16:06:01	11	81	34	47	50	82	58	48
16:06:03	2	81	35	82	51	47	91	48
16:06:22	68	81	106	79	155	82	178	78
16:06:24	83	79	113	81	123	78	230	82
16:06:26	94	81	98	79	138	78	205	82
16:06:28	69	81	113	79	161	78	162	82
16:06:29	66	81	122	79	153	82	154	78

Table 2

LEAST-SQUARES ERRORS [LSE] AND MOST LIKELY DISCHARGE LOCATIONS [MLDL] FOR DISCHARGES OCCURRING AT TIMES IN COLUMN 1 (continued)

INTEGRAL PARAMETERS								
Time	Min LSE	MLDL	2nd Min LSE	2nd MLDL	3rd Min LSE	3rd MLDL	4th Min LSE	4th MLDL
15:59:08	203	24	294	27	494	10	794	9
15:59:11	290	27	683	24	1042	26	1074	10
15:59:13	166	27	381	24	462	10	664	26
15:59:15	266	10	289	11	442	9	445	24
15:59:17	225	24	270	27	498	10	810	9
15:59:34	213	24	354	10	426	27	586	9
15:59:36	212	24	377	10	433	27	598	11
15:59:38	213	24	354	10	426	27	586	9
15:59:40	307	24	340	10	426	27	473	11
16:00:20	489	68	506	12	635	72	662	11
16:00:22	462	68	531	11	659	12	706	72
16:00:24	371	12	562	72	634	68	885	11
16:00:42	427	57	643	62	651	58	669	67
16:00:43	385	57	597	58	597	62	747	67
16:00:45	418	62	570	57	840	58	926	67
16:00:47	450	59	462	57	542	67	654	58
16:00:49	358	62	488	57	742	58	934	67
16:01:09	73	3	98	1	325	4	467	2
16:01:11	147	1	278	3	282	2	602	4
16:01:13	86	1	93	3	365	4	419	2
16:01:15	74	3	91	1	310	4	430	2
16:01:17	85	3	120	1	291	4	477	2
16:01:35	137	20	358	23	1422	25	1578	63
16:01:37	110	20	345	23	1471	25	1567	63
16:01:39	372	20	923	23	1493	63	1845	25
16:01:41	100	20	331	23	1477	25	1613	63
16:01:43	806	20	1855	23	2853	63	3825	25
16:02:14	75	7	145	56	364	58	558	57
16:02:16	107	7	149	56	300	58	490	57
16:02:18	90	7	146	56	331	58	523	57
16:02:20	42	7	138	56	423	58	609	57
16:02:22	140	7	188	56	285	58	479	57
16:02:56	19	89	183	46	193	82	209	48
16:02:58	67	46	99	89	111	48	207	47
16:03:00	30	90	85	41	130	40	155	47
16:03:02	19	89	161	82	198	90	217	48
16:03:04	19	89	161	82	198	90	217	48
16:03:31	551	36	1011	34	1052	79	1395	78
16:03:33	642	33	759	77	852	36	1045	79
16:03:35	716	36	807	79	1094	33	1269	77
16:03:37	577	33	700	77	783	36	1046	79

Table 2
LEAST-SQUARES ERRORS [LSE] AND MOST LIKELY DISCHARGE LOCATIONS [MLDL] FOR DISCHARGES OCCURRING AT TIMES IN COLUMN 1 (continued)

16:03:38	577	33	700	77	783	36	1046	79
16:04:14	354	77	375	33	1141	36	1498	32
16:04:16	211	77	218	33	888	36	1191	32
16:04:18	265	77	326	33	438	30	773	32
16:04:19	351	77	406	33	1168	36	1437	79
16:04:21	345	77	362	33	1090	36	1465	79
16:04:46	24	47	46	91	46	48	81	45
16:04:47	41	48	67	46	105	47	117	91
16:04:49	50	48	54	46	122	47	132	91
16:04:51	43	46	61	48	141	47	149	91
16:04:53	5	48	29	47	45	91	123	46
16:05:09	52	97	53	94	77	49	84	50
16:05:11	18	44	42	50	57	51	77	94
16:05:15	16	44	26	50	41	51	58	96
16:05:17	16	44	26	50	41	51	58	96
16:05:19	16	44	26	50	41	51	58	96
16:05:21	37	97	56	94	62	49	69	50
16:05:56	65	54	122	95	401	55	901	97
16:05:57	26	54	65	95	290	55	730	97
16:05:59	64	54	121	95	400	55	900	97
16:06:01	101	54	170	95	485	55	1025	97
16:06:03	16	54	49	95	256	55	676	97
16:06:22	258	78	309	81	487	79	525	82
16:06:24	165	79	626	78	699	77	1039	81
16:06:26	162	79	668	77	675	78	1062	81
16:06:28	254	79	313	78	520	81	840	82
16:06:29	279	81	294	78	463	82	565	79

Table 2
LEAST-SQUARES ERRORS [LSE] AND MOST LIKELY DISCHARGE LOCATIONS [MLDL] FOR DISCHARGES OCCURRING AT TIMES IN COLUMN 1 (continued)

AMPLITUDE AND INTEGRAL PARAMETERS								
Time	Min LSE	MLDL	2nd Min LSE	2nd MLDL	3rd Min LSE	3rd MLDL	4th Min LSE	4th MLDL
15:59:08	728	27	1604	24	3111	10	3639	26
15:59:11	880	27	2096	24	3599	10	3767	26
15:59:13	531	27	1859	24	3048	10	3450	26
15:59:15	971	27	1893	24	2712	10	3468	26
15:59:17	681	27	1727	24	3322	10	3838	26
15:59:34	1238	24	1340	27	2147	10	2459	26
15:59:36	1268	24	1378	27	2191	10	2453	26
15:59:38	1310	24	1356	27	2095	10	2359	26
15:59:40	1276	27	1473	10	1536	24	2226	9
16:00:20	603	12	780	72	947	11	951	68
16:00:22	774	11	776	12	861	72	866	68
16:00:24	468	12	707	72	1096	68	1170	11
16:00:42	625	57	842	59	999	62	1013	58
16:00:43	591	57	885	62	932	59	967	58
16:00:45	701	57	739	62	1105	58	1268	59
16:00:47	523	59	636	57	860	56	947	67
16:00:49	619	57	679	62	1007	58	1332	59
16:01:09	99	3	159	1	807	2	1464	4
16:01:11	197	1	315	3	651	2	1808	4
16:01:13	130	3	136	1	788	2	1571	4
16:01:15	111	3	141	1	799	2	1516	4
16:01:17	111	3	181	1	817	2	1430	4
16:01:35	151	20	739	23	3108	63	4662	26
16:01:37	124	20	726	23	3097	63	4751	26
16:01:39	446	20	1236	23	2851	63	5353	25
16:01:41	114	20	712	23	3143	63	4721	26
16:01:43	860	20	2184	23	4237	63	7427	25
16:02:14	88	7	645	58	1025	57	1115	56
16:02:16	112	7	565	58	941	57	1111	56
16:02:18	94	7	603	58	981	57	1107	56
16:02:20	43	7	664	58	1026	57	1038	56
16:02:22	150	7	583	58	973	57	1213	56
16:02:56	164	89	218	48	262	82	312	47
16:02:58	127	48	188	46	207	47	221	89
16:03:00	164	47	174	90	212	48	320	89
16:03:02	141	89	215	82	233	48	279	90
16:03:04	141	89	215	82	233	48	279	90
16:03:31	1997	33	2266	79	2892	37	2919	77
16:03:33	1202	33	1868	77	2171	79	2548	32
16:03:35	1513	33	1972	79	2171	77	3311	32
16:03:37	1162	33	1828	77	2121	79	2458	32

Table 2
LEAST-SQUARES ERRORS [LSE] AND MOST LIKELY DISCHARGE LOCATIONS [MLDL] FOR DISCHARGES OCCURRING AT TIMES IN COLUMN 1 (concluded)

16:03:38	1291	33	2029	77	2256	79	2455	32
16:04:14	432	33	508	77	2272	32	3281	79
16:04:16	270	33	348	77	1952	32	2782	31
16:04:18	379	33	409	77	1489	31	1530	29
16:04:19	465	33	523	77	2265	32	3082	79
16:04:21	407	33	499	77	2195	32	3082	79
16:04:46	25	47	71	48	167	91	261	90
16:04:47	45	48	109	47	181	91	236	46
16:04:49	54	48	126	47	196	91	223	46
16:04:51	65	48	145	47	212	46	213	91
16:04:53	21	48	29	47	145	91	244	46
16:05:09	57	94	61	97	81	49	88	50
16:05:11	46	50	81	94	97	49	105	96
16:05:15	30	50	63	94	73	49	83	96
16:05:17	30	50	63	94	73	49	83	96
16:05:19	30	50	63	94	73	49	83	96
16:05:21	46	97	60	94	66	49	73	50
16:05:56	1919	95	2214	54	2378	97	2459	55
16:05:57	1956	95	2277	54	2293	97	2430	53
16:05:59	1926	95	2221	54	2385	97	2466	55
16:06:01	2228	95	2535	54	2739	97	2822	55
16:06:03	1940	95	2239	97	2267	54	2344	53
16:06:22	377	81	436	78	593	79	680	82
16:06:24	248	79	749	78	1152	81	1765	82
16:06:26	260	79	813	78	1156	81	1779	82
16:06:28	367	79	474	78	589	81	1002	82
16:06:29	345	81	448	78	616	82	687	79

- Location Interpolation Based on Error Analyses. The characterization matrix was generated by stimulating discrete points on the vehicle surface. Since discharges in space are unlikely to occur at exactly those points, error analysis techniques can be used to interpolate between those points to estimate more precisely the actual discharge location. Techniques for accomplishing such estimates will be explored and implemented.
- Source Amplitude Estimation. Once the location has been determined from the above analyses, estimates of the actual characteristics of the radiated fields generated at the discharge location can be obtained by extrapolation to the source from the measured E-field data. Algorithms to perform this task will be implemented.
- Integration of Processing Algorithms. An effort will be made to combine and automate the overall data handling and analyses tasks to automate and simplify flight-data processing.